Water Resources Research Center
Annual Technical Report
FY 2008

Introduction

The University of Arizona's Water Resources Research Center (WRRC) promotes understanding of critical state and regional water management and policy issues through research, community outreach and public education. A research and extension unit of the College of Agriculture and Life Sciences, the UA's WRRC is the designated state water resources research institute established under the 1964 Federal Water Resources Research Act. It is also one of five UA centers responsible for implementing the Water Sustainability Program, which receives funding from the UA’s Technology and Research Initiative Fund. In addition to conducting water management and policy research, the WRRC has a strong information transfer program that includes community outreach, publications, presentations, conferences, seminars and workshops.

Research Program Introduction

The University of Arizona's Water Resources Research Center manages a research grant and information transfer program under the Water Resources Research Act, Section 104(b). The WRRC typically funds three or four small projects each year. Researchers in the social, biological, physical and engineering sciences, including such fields as water management, water law, economics and public health, from the three Arizona universities are invited to apply for grants. A wide range of projects have been funded over the past 40 years. In recent years, projects have emphasized improvements in water supply quality and reliability, and explored new ideas to address water problems in Arizona or expand understanding of water and water-related phenomena. A primary goal of the program is to foster the entry of new research scientists, engineers, and technicians in the water resources field. The program also promotes dissemination of research results to water managers and the public.

The WRRC manages a research program under the United States-México Transboundary Aquifer Assessment Act of 2006, which mandates the assessment of priority aquifers along the U.S. – Mexico border through the appropriation of up to $50 million over 2007 – 2016. Since 2007 the Water Resources Research Institutes of Arizona, New Mexico, and Texas, and the United States Geological Survey (USGS) in partnership with the International Boundary and Water Commission (IBWC) have been developing binational collaboration with Mexican federal, state, and local agencies to undertake hydrogeologic characterization, mapping, modeling, and institutional assessment of priority aquifers. The two priority aquifers is Arizona are the Santa Cruz aquifer and San Pedro aquifer – shared by Arizona and the Mexican state of Sonora.

The WRRC also and administers competitive grants funded by the U.S. Geological Survey under Section 104(g).

Forward and Inverse Transient Analytic Element Models of Groundwater Flow

Basic Information

Title:	Forward and Inverse Transient Analytic Element Models of Groundwater Flow
Project Number:	2004AZ68G
Start Date:	9/1/2004
End Date:	8/31/2008
Funding Source:	104G
Congressional District:	7th
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Hydrology, Models
Descriptors:	Ground-water, Hydrology, Models
Principal Investigators:	Shlomo P. Neuman

Publication

1. Kuhlman, Kristopher L. and Shlomo P. Neuman. Recent advances in Laplace transform analytic element method (LT-AEM) theory and application to transient groundwater flow , In Computation Methods in Water Resources, Volume XVI, 2006.
2. Kuhlman, K.L. and S.P. Neuman, Recent advances in Laplace-transform analytic element method (LT-AEM) theory and application to transient groundwater flow, Proc. XVIth Intern. Conf. Computational Methods in Water Resources XVI (CMWR XVI) June 2005, Copenhagen, 2006.
3. Kuhlman, Kristopher L., 2008, Laplace Transform Analytic Element Method for Transient Groundwater Flow Simulation, Ph.D. Dissertation," Department of Hydrology and Water Resources, Graduate College, The University of Arizona, Tucson, Arizona, 239 pp.
4. Kuhlman, K.L., and S.P. Neuman, 2009, Laplace transform analytic element method for porous media flow, Journal of Engineering Mathematics , 64(2), 113-130.
5. Kuhlman, K.L., and A.W. Warrick, 2008, Quasilinear infiltration from an elliptical cavity, Advances in Water Resources, 31(8), 1057-1065.
6. Kuhlman, K.L., A.C. Hinnell, P.K. Mishra, and T.-C.J. Yeh, 2008, Basin-scale transmissivity and storativity estimation using hydraulic tomography, Ground Water, 46(5), 706-715.
7. Kuhlman, K.L., and S.P. Neuman, 2007, Recent advances in Laplace transform analytic element method (LT-AEM) theory and application to transient groundwater flow in EOS Transactions of the American Geophysical Union, 87(52), Fall Meeting Supplement, Abstract H41B-0397.
8. Kuhlman, K.L., and S.P. Neuman, 2007, Transient Analytic Element Solutions for Flexible Aquifer Test Analyses, in EOS Transactions of the American Geophysical Union, 88(52), Fall Meeting Supplement, Abstract H23I-08.

Description Information

Problem and Research Objectives

The traditional Analytic Element Method (AEM) and the Laplace transform AEM (LT-AEM) partially fill a gap in available modeling tools between analytic solutions derived for simple geometries (e.g., radially-symmetric flow to a well) and distributed-parameter gridded models (e.g., finite element or finite difference methods). AEM and LT-AEM provide flexibility and computational efficiency, while retaining the accuracy and much of the elegance of an analytic solution.

The Laplace transform analytic element method (LT-AEM) applies the traditional steady-state analytic element method (AEM) to the Laplace-transformed diffusion equation (Furman and Neuman, 2003). This strategy preserves the accuracy and elegance of the AEM while extending the method to transient phenomena.

The approach we have taken utilizes eigenfunction expansion to derive analytic solutions to the modified Helmholtz equation, then back-transforms the LT-AEM results into the time domain with a numerical inverse Laplace transform algorithm. We derived two-dimensional elements including point, circle, line segment, ellipse and infinite line corresponding to polar, elliptical and Cartesian coordinates. Each element was derived for the simplest case of practical relevance: an impulse response due to a confined, transient, single-aquifer source. Extensions to situations involving leakage, presence of a water table, multiple aquifers, wellbore storage and inertia were demonstrated for a few simple elements (point and line) but is readily applied to other elements. General temporal behavior was achieved using convolution between such impulse and general time functions; convolution allows the spatial and temporal components of an element to be handled independently.

Methodology

LT-AEM is based on superposition and convolution. Separation of variables and eigenfunction expansion are used to derive elements satisfying the governing equation. After deriving the elements and combining them to solve more general problems with superposition and convolution, desired boundary conditions must be enforced using the AEM process of boundary matching, in a way that allows evaluating all relevant coefficient. Head or flux are then calculated in a straightforward manner based on the known coefficients.

Specific two-dimensional LT-AEM elements were derived for circular, elliptical and Cartesian coordinates. Some discussion regarding the extension of the methods to 3D problems was outlined, but not fully pursued. As an extension to the 2D elements, we used general methods for deriving distributed source terms. Homogeneous source terms of interest to hydrologists were derived including leaky, multi-layer, unconfined and damped wave source terms.

The inverse Laplace transform algorithm is the most crucial component to the success of LT-AEM. We outlined and compared several inverse algorithms such as Post-Widder, Schapery, Fourier series and Möbius transformation approaches.

Our results include two inverse-modeling applications of LT-AEM. One concerns interpretation of a two-well unconfined aquifer test near a river using PEST (Doherty, 2007). The other estimates the geometry associated with a synthetic problem using SCEM-UA (Vrugt et al., 2003).

Principal Findings and Significance

The introductory LT-AEM work of Furman and Neuman (2003) was generalized and extended to include additional circular elements which illustrate the applicability of LT-AEM to aquifer test interpretation. The approach utilized elliptical LT-AEM elements, corresponding to the most general 2D coordinate system within which the modified Helmholtz equation can be solved via eigenfunction expansion. For a few geometries eigenfunction expansion is a powerful and elegant method for deriving LT-AEM elements.

The LT-AEM methodology (eigenfunction expansion + numerical inverse Laplace transformation) was used to solve leaky, unconfined, multi-layer and damped-wave flow problems. These exemplify how LT-AEM can be extended to more general aquifer test analysis scenarios; dual porosity may be similarly handled. Transient multi-source aquifer tests including inhomogeneities, finite leaky layers, nearby boundaries and rivers that would previously have required the use of numerical models based on finite differences or finite elements can now be analyzed using the LT-AEM.

Chemolithotrophic denitrification: The missing link in the biogeochemical cycle of arsenic

Basic Information

Title:	Chemolithotrophic denitrification: The missing link in the biogeochemical cycle of arsenic
Project Number:	2005AZ114G
Start Date:	9/1/2005
End Date:	8/31/2008
Funding Source:	104G
Congressional District:	AZ05
Research Category:	Water Quality
Focus Category:	Treatment, Groundwater, Toxic Substances
Descriptors:	Arsenic, arsenate, arsenite, microbial transformation, denitrification
Principal Investigators:	Reyes Sierra, James Field, Ronald S Oremland

Publication

1. Sierra-Alvarez, R., W. Sun, P. Rowlette, I. Cortinas and JA Field. 2005. Anoxic Oxidation of Arsenite Linked to Denitrification. Eighth International In Situ and On-Site Bioremediation Symposium. June 6-9, 2005. Baltimore, MD. (Conference proceedings).
2. Sun, W., R. Sierra-Alvarez, N. Fernandez, J. L. Sanz, R. Amils, A. Legatzki, R. Maier and J. A. Field. 2009. Molecular characterization and in situ quantification of anoxic arsenite oxidizing denitrifying enrichment cultures. FEMS Microb. Ecol. 68:72-85.
3. Sun, W., R. Sierra-Alvarez, and J. A. Field. 2008. Anoxic oxidation of arsenite linked to denitrification in sludges and sediments. Water Res. 42(17):4569 – 4577.
4. Sun, W., R. Sierra-Alvarez, L. Milner, R. Oremland and J. A. Field. 2009. Arsenite and Ferrous iron oxidation linked to chemolithotrophic denitrification for the immobilization of arsenic in anoxic environments. Environ. Sci. Technol. (Under review).
5. Sun, W. 2008. Microbial oxidation of arsenite in anoxic environments: Impacts on arsenic mobility. Ph.D Dissertation, Department of Chemical and Environmental Engineering, College of Engineering, The University of Arizona, Tucson, Arizona. 337 pp.

2. Descriptive Information:

A. Problem and Research Objectives:

Although arsenic (As) has a relatively low abundance in the earth's crust, it is generally found as a contaminant in soil and water systems due to various anthropogenic activities, such as mining, discharge of industrial waste and agriculture, as well as from natural biogeochemical reactions (ATSDR, 2007; Oremland & Stolz, 2003; Smedley & Kinniburgh, 2002). Arsenic is a known human carcinogen (ATSDR, 2007), and its contamination of drinking water sources is presently a worldwide concern (Smedley & Kinniburgh, 2002). The predominant species of As found in surface water and groundwater are arsenite (As(III), H_3AsO_3) and arsenate (As(V), $H_2AsO_4^-$ and $HAsO_4^{2-}$). In natural soil and sediments, iron (Fe) (hydr)oxides strongly sorb both As(III) and As(V) in circumneutral pH environments (Dixit & Hering, 2003; Raven et al., 1998)

The mobility of As in the environment is highly influenced by microbial transformations, which affect As and Fe speciation (Oremland & Stolz, 2003). A large diversity of anaerobic microorganisms have been discovered that reduce As(V) to As(III). The formation of As(III) from the microbial reduction of As(V) increases public health risk, because As(III) is generally considered to be the more mobile and toxic form of As (Smedley & Kinniburgh, 2002; Sierra-Alvarez et al., 2004). Furthermore, dissimilatory reductive dissolution of ferric (Fe(III)) (hydr)oxides, a process know to occur in anaerobic environments, could also lead to release of adsorbed As (Anawar et al. 2006; Cummings et al., 1999; Oremland et al. 2005), posing a threat of As contamination in drinking water (Anawar et al., 2006; Smedley &Kinniburgh, 2002).

Microorganisms from physiologically diverse groups, including both heterotrophs and autotrophs, can oxidize As(III) to As(V) in the presence of elemental oxygen (O_2) in various environments (Stolz et al., 2006; Inskeep et al., 2007). Recent evidence also indicates that nitrate-reducing bacteria can oxidize As^{III} in anoxic environments (Oremland et al., 2002; Rhine et al., 2006). Microbial oxidation of both soluble and insoluble Fe(II) coupled to nitrate reduction has also been demonstrated in various freshwater and saline environmental systems at neutral pH (Weber et al., 2006a; Straub et al., 2004). The biological oxidation of Fe(II) results in the formation of insoluble Fe(III) (hydr)oxide minerals in anoxic soils and sediments, such as ferrihydrite and other forms of iron oxides (Weber et al., 2006b). These biogenic iron oxides have the potential to adsorb arsenic.

The objective of this study is to evaluate the importance of chemolithotrophic denitrifying bacteria in the biogeochemical cycle of arsenic. The proposed research will examine the direct microbial oxidation of As(III) with nitrate as electron acceptor, as well as the microbial oxidation of Fe(II) with nitrate and subsequent adsorption of As(V) by the iron oxides formed. The central question addressed in this proposal is whether anoxic oxidations of As(III) and Fe(II) are ubiquitous process in groundwater and surface waters controlling the mobility of arsenic.

B. Methodology:

Microorganisms: Sludge and sediment samples obtained from different locations were used as inocula in the batch bioassays. Aerobic activated sludge (RAS) and anaerobically digested

sewage sludge (ADS) were obtained from a local municipal wastewater treatment plant (Ina Road, Tucson, AZ). Methanogenic granular sludge (biofilms pellets) samples were obtained from industrial upward-flow anaerobic sludge blanket (UASB) treatment plants treating recycled paper wastewater (EGS) (Industriewater, Eerbeek, The Netherlands) and alcohol distillery wastewater (NGS) (Nedalco, Bergen op Zoom, The Netherlands). Chemolithotrophic denitrifying granular sludge was obtained from a laboratory-scale thiosulfate-oxidizing denitrifying enrichment bioreactor (TDE) (Dept. Chemical and Environmental Engineering (ChEE), University of Arizona). Duck pond sediments were obtained at the Agua Caliente Park (DPS) (Tucson, AZ). Additional sediments were also collected from Pinal Creek (PCS) (AZ) and from a Winogradsky column (WCS) (from ChEE) originally inoculated with a mixture of cattle manure lagoon sludge mixed with creek sediments obtained in Patagonia, AZ.

Details of other experimental methods utilized in this study are provided elsewhere (Sun et al. 2008 and 2009).

C. Principal Findings and Significance:

Anoxic Oxidation of Arsenite Linked to Denitrification in Sludges and Sediments

In this study, denitrification linked to the oxidation of arsenite (As(III)) to arsenate (As(V)) was shown to be a widespread microbial activity in anaerobic sludge and sediment samples that were not previously exposed to arsenic contamination (Table 1). When incubated with 0.5 mM As(III) and 10 mM nitrate, the anoxic oxidation of As(III) commenced within a few days (Figure 1), achieving specific activities of up to 1.24 mmol As(V) formed g^{-1} volatile suspended solids d^{-1} due to growth (Table 2). The doubling times for growth of the anoxic As(III) oxidizers range from 0.74 to 1.34 d. The anoxic oxidation of As(III) was partially to completely inhibited by 1.5 and 5.0 mM As(III), respectively. Inhibition was minimized by adding As(III) adsorbed onto activated aluminum (AA). The oxidation of As(III) was shown to be linked to the complete denitrification of nitrate to dinitrogen gas (N_2) by demonstrating a significantly enhanced production of N_2 beyond the background endogenous production as a result of adding As(III)–AA to the cultures. The N_2 production corresponded closely the expected stoichiometry of 2.5 mol As(III) mol^{-1} N_2–N corresponding to complete denitrification as shown in equation 1 below:

$$5AsO_3H_3 + 2NO_3^- + 2H^+ \rightarrow 5AsO_4H_3 + N_2 + H_2O \qquad [1]$$

These results demonstrate that microorganisms capable of linking anoxic As(III) oxidation to denitrification are widespread in anaerobic sediments and sludges. Furthermore, they suggest that the oxidation of As(III) linked to the use of common-occurring nitrate as an electron acceptor may be an important missing link in the biogeochemical cycling of arsenic between two common inorganic species, As(III) and As(V), where DO is absent.

Table 1 – Summary of microbial As(III) oxidation under denitrifying conditions

Inoculum		As(V) formation[b]		Time[a] (d)
Number	Sources	With NO_3^-	Without NO_3^-	
1	NGS	0.423 ± 0.004	—	6
2	EGS	—	—	—
3	ADS	0.425 ± 0.003	—	13
4	RAS	—	—	—
5	TDE	0.416 ± 0.002	—	10
6	DPS	0.415 ± 0.003	—	6
7	WCS	0.413 ± 0.001	—	5
8	PCS	0.295 ± 0.020	0.298 ± 0.014	>14[c]

As(V) formation = concentration of As(V) (at the end of the experiment, d10 or d14) – concentration of As(V) (at d0).

a Time to oxidize 80% of 0.5 mM As(III) to As(V).

b Conversion of As(III) to As(V): "average ± STDE" for "conversion ≥ 80%"; "—" for "conversion ≤ 5%".

c In PCS, at d14 only 60% of As(III) was converted to As(V).

Table 2 – Summary of kinetics[a] of microbial As(III) oxidation (0.5 mM) under denitrifying conditions

Inoculum sources	Doubling time (d)[b]	Highest specific activity (mmol As(V) g^{-1} VSS_{added} d^{-1})
NGS	0.744 ± 0.027	1.243 ± 0.045
ADS	1.041 ± 0.028	0.160 ± 0.004
DPS	1.145 ± 0.106	0.609 ± 0.060

a Estimated from As(V) formation data.

b The coefficient of determination (R^2) was 0.9972, 0.9804 and 0.9741 for the ln(ΔAs(V)) versus time plots of NGS, ADS and DPS.

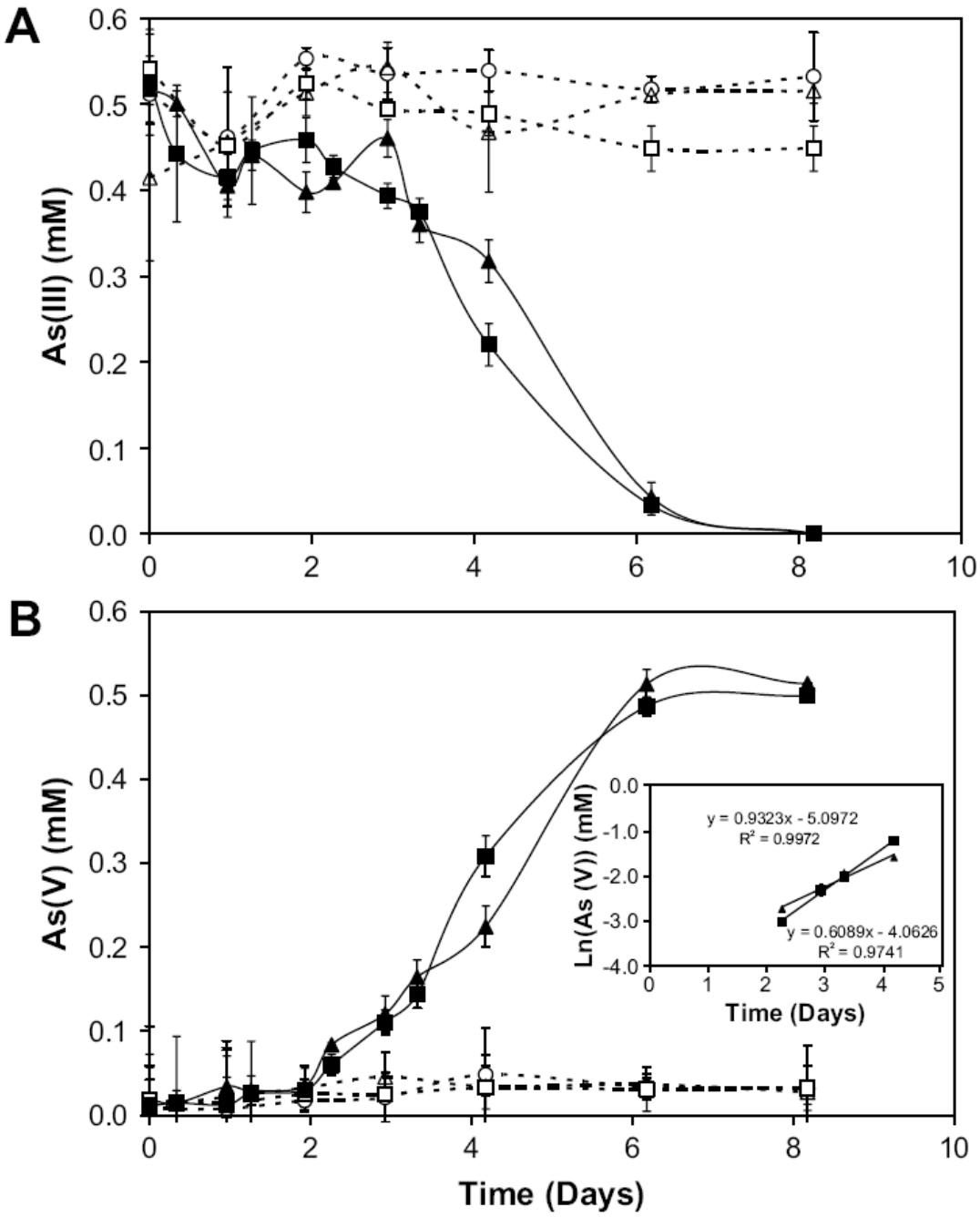

Figure 1 – The removal of As(III) (panel A) and formation of As(V) (panel B) by NGS and DPS under denitrifying condition, NGS and DPS with nitrate (■) and (▲), NGS without nitrate (□) and (Δ), abiotic (○). Insert shows natural logarithm plot of data during exponential growth phase.

Arsenite and Ferrous Iron Oxidation Linked to Chemolithotrophic Denitrification for the Immobilization of Arsenic in Anoxic Environments

The objective of this study was to explore a bioremediation strategy based on injecting nitrate to support the anoxic oxidation of ferrous iron (Fe(II)) and As(III) in the subsurface as a means to immobilize As in the form of As(V) adsorbed onto biogenic ferric (Fe(III)) (hydr)oxides. Continuous flow columns packed with sand were used to simulate a natural anaerobic groundwater and sediment system with co-occurring As(III) and Fe(II) in the presence (column SF1) or absence (column SF2) of nitrate, respectively. During operation for 250 days, the average influent arsenic concentration of 567 μg l^{-1} was reduced to 10.6 μg l^{-1} in the effluent of column SF1 (Figure 2). The cumulative removal of Fe(II) and As(III) in SF1 was 6.5-10.0-fold higher than that in SF2 (Figures 2 and 3). Extraction and measurement of the mass of iron and arsenic immobilized on the sand packing of the columns was close to the iron and arsenic removed from the aqueous phase during column operation. The dominant speciation of the immobilized iron and arsenic was Fe(III) and As(V) in SF1, compared with Fe(II) and As(III) in SF2. The speciation was confirmed by XR diffraction and X-ray photoelectron spectroscopy (XPS) (Figure 4).

These results indicate that the biological denitrification activity in column played an important role in the immobilization process of Fe and As since the only difference in the set up of SF1 and SF2 was the lack of nitrate in the feed of the latter column. Furthermore, they suggest that immobilization of As on iron (hydr)oxides in anoxic environments occurs through a two-step process: firstly, formation of Fe(III) (hydr)oxides due to nitrate-dependent Fe(II) oxidation, and secondly, subsequent adsorption or co-precipitation of arsenic.

Implications. Fe(III) (hydr)oxides adsorb both As(V) and As(III) and, thus, offer significant potential in controlling the dissolved As concentrations in natural environments. Anaerobic microbial reduction and dissolution of Fe(III) (hydr)oxides, as well as dissimilitary reduction of As(V) to As(III) are major mechanisms of mobilizing As in soil and sediments (Anawar et al. 2006; Oremland and Stolz, 2005). Fe(II) and As(III) commonly co-occur in contaminated groundwater and surface water under anaerobic conditions. The reversal of the process by the oxidation of Fe(II) and As(III) could be an important bioremediation strategy to generate Fe(III) (hydr)oxides that immobilize As(V) on the solid phases. Although dissolved oxygen can readily oxidize Fe(II) and As(III) abiotically and biologically, respectively, it is difficult to diffuse dissolved oxygen into anoxic zones of the submerged subsurface due to its low solubility and high reactivity. However, nitrate could be utilized as an alternative electron acceptor with advantages of having a high solubility, and lower reactivity, which will enable it to disperse in the saturated subsurface. The study presented here validates that microbial nitrate-dependent oxidation of Fe(II) and As(III) enhances the immobilization of As in the anoxic environments.

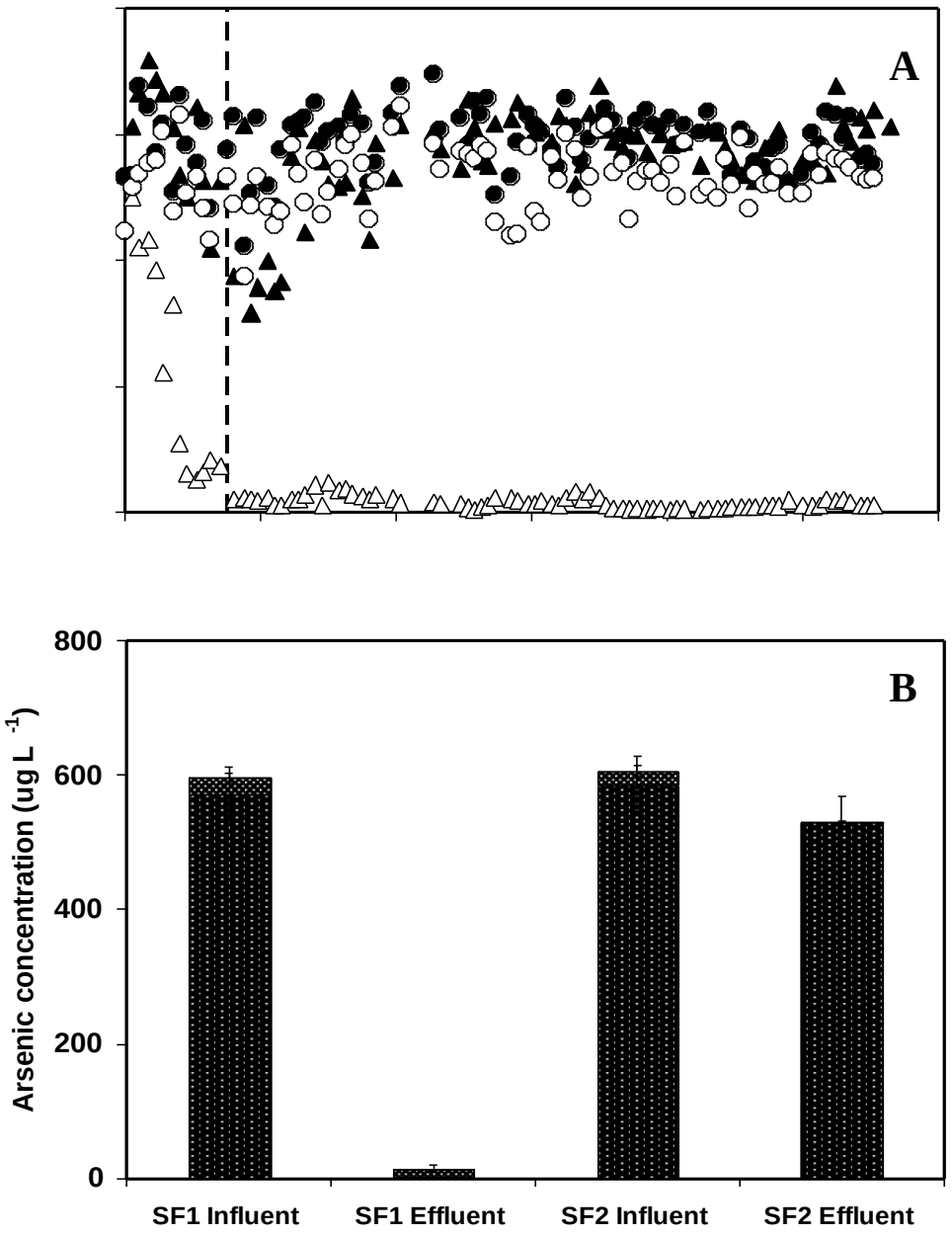

Figure 2 Panel A, removal of soluble total As in two sand packed columns fed with a mineral medium containing 6.7 μM As(III) and 36 μM Fe(II). Column SF1 (fed with 2.5 mM nitrate): (▲) influent, (Δ) effluent; Column SF2 (without nitrate): (●) influent, (○) effluent. The dish line indicates the day when the steady state operation was achieved; panel B**,** arsenic speciation in the influent and effluent of sand packed columns starting from at 30 when steady status was achieved.

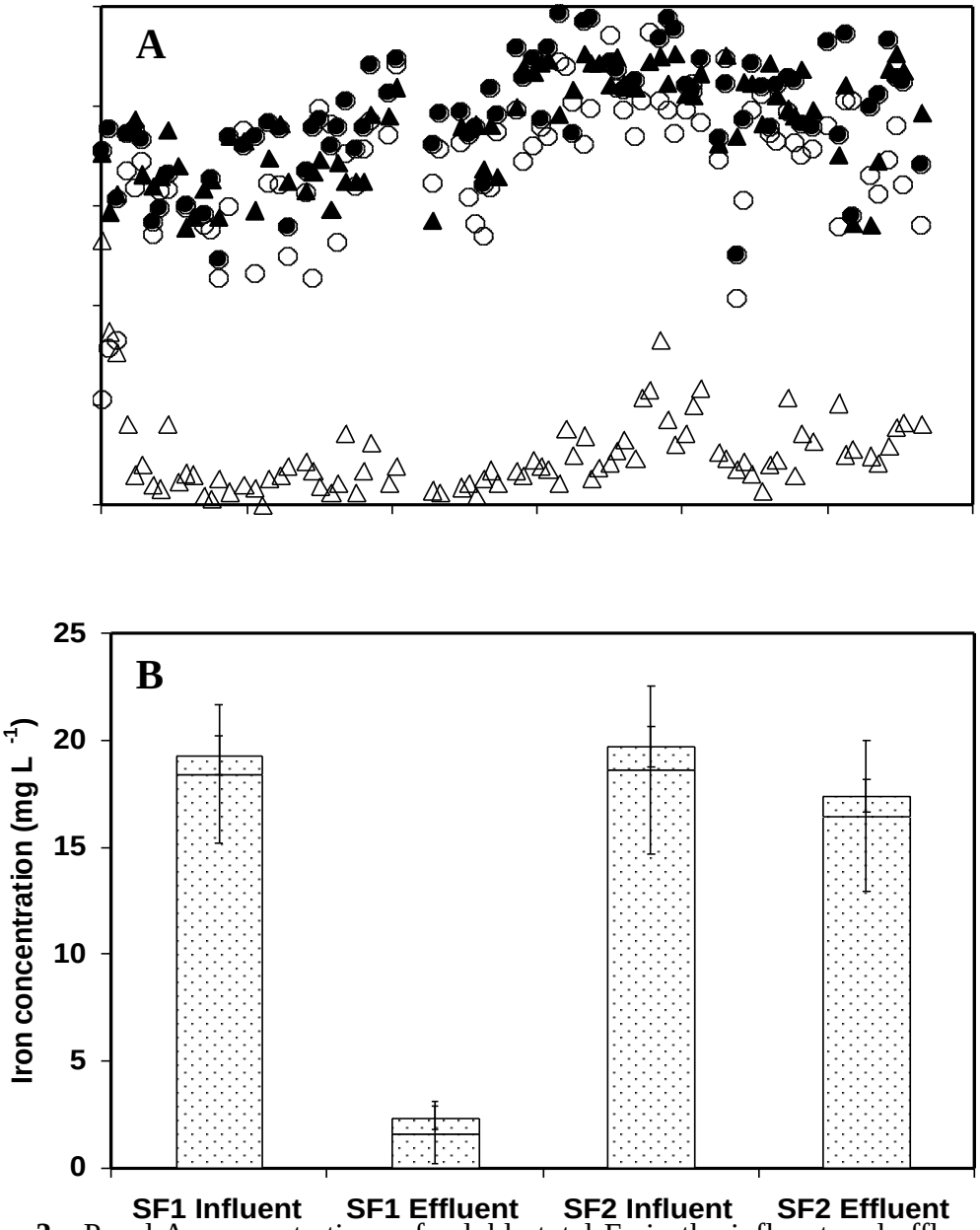

Figure 3 - Panel A, concentrations of soluble total Fe in the influent and effluent of biological column SF1 as a function of time: Column SF1 (fed with 36 μM Fe(II), 6.7 μM As(III) and 2.5 mM nitrate): (▲) influent, (Δ) effluent; Column SF2 (fed with 36 μM Fe(II) and 6.7 μM As(III) without nitrate): (●) influent, (○) effluent; panel B, iron speciation in the influent and effluent of sand packed columns supplied with 6.7 μM As(III), 36 μM Fe(II) and 2.5 mM nitrate (column SFF1), or only 6.7 μM As(III) and 36 μM Fe(II) (column SF2): Fe(II) (solid block) and Fe(III) (empty block).

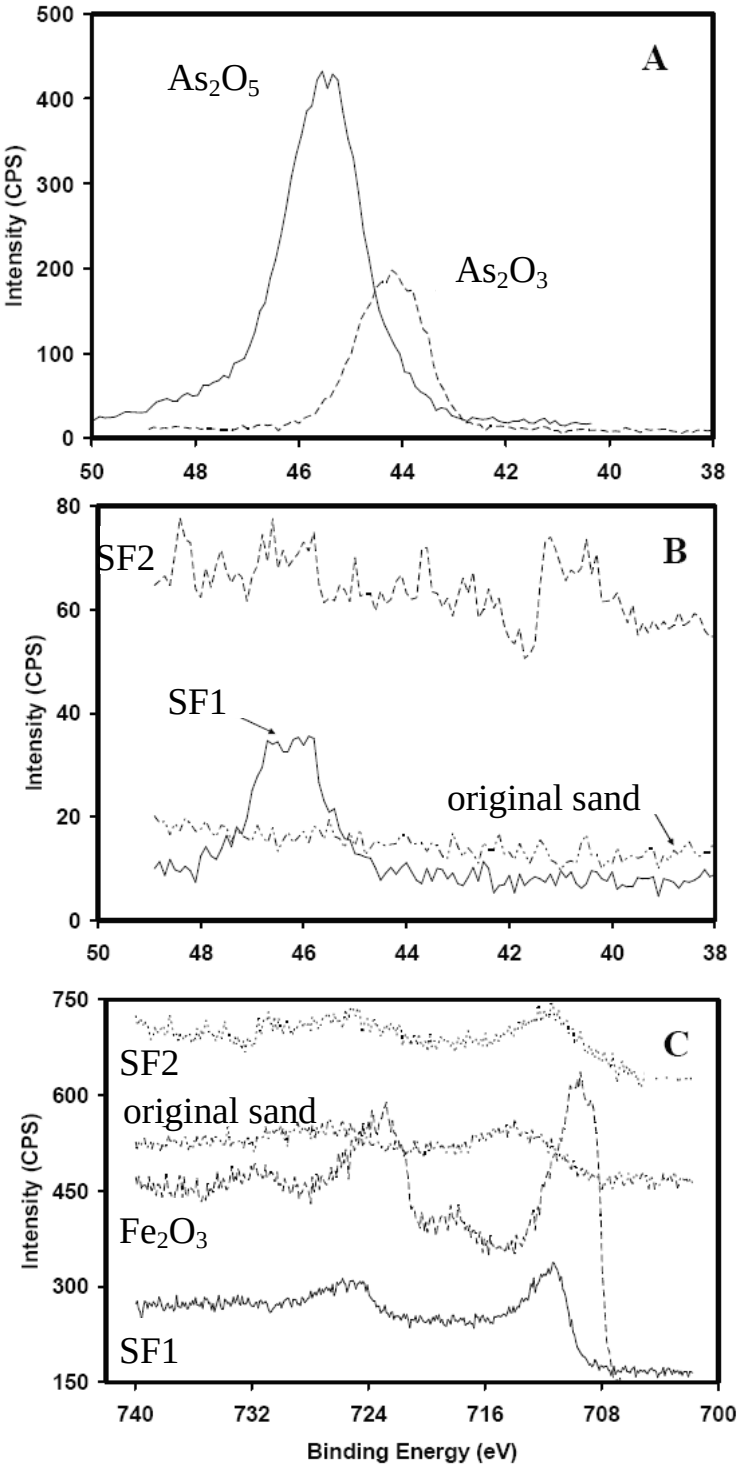

Figure 4. XPS for original sand, SF1 and SF2 column profile: arsenic standards (panel A), arsenic samples (panel B), and iron standard with samples (panel C).

Molecular Characterization and In Situ Quantification of Anoxic Arsenite-Oxidizing Denitrifying Enrichment Cultures

To explore the bacteria involved in the oxidation of arsenite under denitrifying conditions, three enrichment cultures (ECs) and one mixed culture (MC) were characterized that originated from anaerobic environmental samples. The oxidation of As(III) (0.5 mM) was dependent on nitrate addition and N_2 formation was dependent on As(III) addition. The ratio of N_2–N formed to As(III) fed approximated the expected stoichiometry of 2.5. A 16S rRNA gene clone library analysis revealed three predominant phylotypes. The first, related to the genus *Azoarcus* from the division β-proteobacteria, was found in the three ECs. The other two predominant phylotypes were closely related to the genera *Acidovorax* and *Diaphorobacter* within the Comamonadaceae family of β-proteobacteria, and one of these was present in all of the cultures examined. Figure 5 shows the relative abundance of 16S rRNA gene phylotypes of clones from each culture with a total of eight unique phylotypes found in the study.

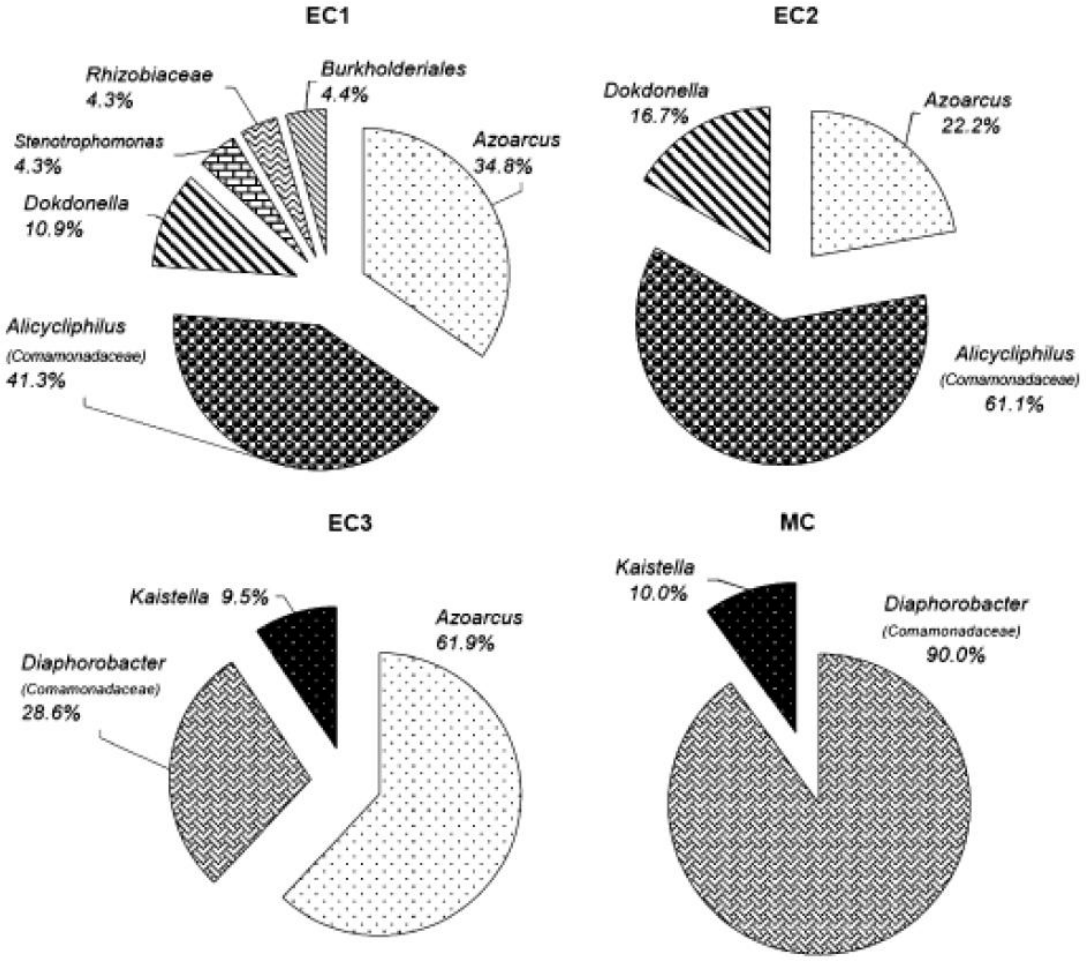

Figure 5 - Phylogenetic distributions in the four cultures. The diagrams show the relative abundance of 16S rRNA gene phylotypes of clones from each culture with a total of eight unique phylotypes found in the study. Out of these eight unique phylotypes, 6, 3, 3 and 2 were found in EC1, EC2, EC3 and the MC, respectively.

FISH confirmed that *Azoarcus* accounted for a large fraction of bacteria present in the ECs. The *Azoarcus* clones had 96% sequence homology with *Azoarcus* sp. strain DAO1, an isolate previously reported to oxidize As(III) with nitrate. FISH analysis also confirmed that Comamonadaceae were present in all cultures. Pure cultures of *Azoarcus* and *Diaphorobacter* were isolated and shown to be responsible for nitrate-dependent As(III) oxidation. These results, taken as a whole, suggest that bacteria within the genus *Azoarcus* and the family Comamonadaceae are involved in the observed anoxic oxidation of arsenite. For *Azoarcus*, this conclusion is supported by the fact that a related isolate from this genus (DAO1) can link As(III) oxidation to denitrification (Rhine et al., 2006) and by the fact that *Azoarcus* sp. strain EC3-pb1 isolated in this study could also carry out the reaction. Furthermore, the closely related isolate EbN1 contains arsenic resistance genes as well as a full set of denitrification genes.

This study is the first report of anoxic As(III) oxidation by members of the Comamonadaceae. A strain of *Diaphorobacter* sp. (Comamonadaceae family), strain MCpb1, was isolated and shown to be able to oxidize As(III) with nitrate. The occurrence of aerobic As(III) oxidizers in the Comamonadaceae cluster (Fan et al., 2008), together with the occurrence of arsenic resistance and denitrification genes in the genome of the closely related *Acidovorax* sp. strain JS42, also supports this potential role.

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Sun, W., R. Sierra-Alvarez, N. Fernandez, J. L. Sanz, R. Amils, A. Legatzki, R. Maier and J. A. Field. 2009. Molecular characterization and in situ quantification of anoxic arsenite oxidizing denitrifying enrichment cultures. *FEMS Microb. Ecol.* 68:72-85.

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Geospatial Analysis of Urban Thermal Gradients: Application to Tucson Arizona s Projected Water Demand

Basic Information

Title:	Geospatial Analysis of Urban Thermal Gradients: Application to Tucson Arizona s Projected Water Demand
Project Number:	2007AZ219B
Start Date:	3/1/2007
End Date:	6/30/2008
Funding Source:	104B
Congressional District:	Seventh
Research Category:	Climate and Hydrologic Processes
Focus Category:	Water Use, Management and Planning, Climatological Processes
Descriptors:	None
Principal Investigators:	Christopher A Scott, Andrew C. Comrie, Stephen Yool

Publication

4. Description Information

A. Problem and Research Objectives

Urban heat island and climate change-driven warming across the Southwest have implications for water use. Researchers and planners have paid inadequate attention to spatial and temporal patterns in urban warming or the implications of these patterns for urban water demands, particularly for outdoor residential irrigation. This study investigated urban warming and water use in the Tucson, Arizona basin. The research objectives were:

1. Characterize spatial (x,y,z) and temporal (t) trends in Tucson's thermal profile from Landsat TM imagery over the period 1984 – 2006. Derive critical threshold temperature exceedances; and for the Spring 2005 period, identify the persistence of warming anomalies.

2. Spatially correlate temperature vs. outdoor water demand (disaggregated from total household demand) and reclaimed water for landscaping, correcting for elevation z, based on 1984 – 2006 (as the historical calibration/ validation phase) followed by future projections through 2030 (in spatially explicit form) and 2050 (in aggregate form).

3. Compile datasets of surface temperature, exceedances and persistence and make them available over the Internet for use by managers, planners, public health officials, ecologists, and researchers.

B. Methodology

Data Sources

i. Archival Landsat Thematic data – accessed from the Arizona Regional Image Archive (aria.arizona.edu). Figure 1 shows the images acquired. Only those images with antecedent precipitation less than 300 mm in the 90-day period preceding the image date as recorded at the Campbell Ave. station were used for analysis in order to minimize the effects of vegetation greening resulting from natural precipitation.

ii. Climatological data – accessed from the National Climatic Data Center (ncdc.noaa.gov) and the Arizona Meteorological Network (ag.arizona.edu/azmet). Table 1 lists the meteorological stations used for the urban warming analysis.

iii. Water use data – quarter section water supply data for 2000-2006 made available by Tucson Water

Landsat images were registered and rectified to an orthophoto-derived street map shapefile from Pima Co. Dept. of Transportation resulting in root mean square error RMSE < 15 m (equivalent to half the minimum pixel resolution). It should be noted that we consider georegistration to have sub-pixel accuracy in the Tucson metropolitan area; however, inadequate control points are expected to reduce this accuracy for Green Valley, Avra Valley, and the Catalina foothills.

Table 1. Meteorological Stations and Data Analyzed

Station	Urban/ Nonurban	Data Analyzed
Campbell Ave. #28796	Urban	Tmin, Tmax, Precip, ET_{ref}
Tucson WFO #28815	Urban	Tmin, Tmax, Precip
Tucson Intl Airport #28820	Urban	Excluded (cold air drainage)
Anvil Ranch #20287	Nonurban	Tmin, Tmax, Precip
Cascabel #21330	Nonurban	Tmin, Tmax, Precip
Oracle 2SE #26119	Nonurban	Tmin, Tmax, Precip
Santa Rita Exp Range #27593	Nonurban	Tmin, Tmax, Precip
Safford #27390	Nonurban	Tmin, Tmax, Precip, ET_{ref}

Vegetation Cover

Normalized difference vegetation index was calculated from TM imagery using atmospherically corrected band 3 (red) and band 4 (near infrared) radiances as follows:

$$NDVI = (B4-B3) / (B4+B3)$$

Atmospheric correction was performed using the COST model (Chavez, 1996).

Thermal Profiles and Gradients

Surface temperatures were retrieved from TM band 6 (thermal infrared) by converting thermal brightness temperatures into thermodynamic (kinetic) temperatures. We accessed an ASTER image from 5/26/2001, with a processed emissivity layer at 90m. The Landsat NDVI for 6/18/2001 (closest date to the ASTER image) was resampled from 30 m to 90 m, and a per-pixel regression of Landsat NDVI vs. ASTER NDVI yielded $R^2 > 0.98$ indicating reliable NDVI results. Subsequently, we regressed ASTER emissivity vs. Landsat NDVI with $R^2 > 0.36$ (see Figure 2) and selected the quadratic equation with the best fit in the NDVI range of interest (0.2 ~ 0.7). Finally, kinetic temperature maps were calculated from emissivity and radiant temperatures as:

$$T_{kinetic} = E^{0.25} * T_{radiant}$$

$T_{kinetic}$ image processing requires additional atmospheric correction of band 6 that we are currently perfecting.

Urban Warming Trend Analysis

Meteorological data from stations listed in Table 1 were analyzed over the 1969-2007 period and the 1984-2005 period (the latter corresponding to the period of Landsat record). Individual

months (Jan., Feb., …) and annual average urban T_{min} and T_{max} were compared to nonurban T_{min} and T_{max} over the entire period of record. The urban – nonurban difference in T_{min} provides the rate of warming resulting from urban heat island processes.

Additional trend analyses were performed on urban and rural reference evapotranspiration (ET_{ref}) for the entire 1987-2007 time series available from the Arizona Meteorological Network.

Water Use in Tucson

Quarter section data of individual months (Jan., Feb., …) and annual total water volumes supplied by Tucson Water were assessed over the 2000-2006 period of record. Because outdoor irrigation is only a fraction of total water supplied, the month of minimum consumption for each year was taken as a proxy for indoor water use for all other months and outdoor water use was derived as the monthly volume less the volume of minimum monthly supply that year. Similar trend analyses were performed for derived outdoor water use.

Public Access to Data Generated by this 104B Project

The project website has been developed to make metadata, data, and processed images available to researchers and agency staff. The website is hosted at:

http://www.dingo.sbs.arizona.edu/~cascott/urbanheat/

We have instituted a brief data download registration protocol, requesting the following information, in order to provide follow up as revised/ final datasets are posted.

Name:
Email:
Which best describes your role? (Choose one): a) University, b) Public agency, c) Private consulting firm, d) Other.
Purpose for the data download (Choose all that apply): i) Water resources assessment, ii) Climate and/or urban heat island research, iii) Urban ecology/ landscaping, iv) Other.

C. Principal Findings and Significance

The NDVI-emissivity quadratic relation shown in Figure 2 is considered robust for the NDVI range of interest (0.2 ~ 0.7). The NDVI time series shown in Figure 3 zoomed in to central Tucson demonstrates urban growth and the resulting maturation of vegetation principally along the southeast-northwest I-10 corridor and in the Catalina foothills. The water demand implications of these trends are explored below.

Quantification of the urban heat island is derived from time series regression of urban - nonurban T_{min}, and is shown in Tables 2 and 3 (and graphically in Figures 5 and 6), for 1969-2006 and the Landsat period of record 1984-2005, respectively. 2004 and 2005 particularly represent warming anomalies for the spring months of February-April. The 1984-2005 urban-nonurban differences are lower than for 1969-2006 for the pre-monsoon period of interest (May and June). Furthermore, the spring 2004 and 2005 T_{min} anomaly mentioned appears to wane for the May

and June months of highest water demand. Additional analysis of NDVI imagery and surface temperatures for established urban development areas within Tucson vs. newly developed areas will permit analysis of the degree to which outdoor irrigation depresses urban temperatures. This has significance for adaptation to warming, but also for Tucson's water budget.

Table 2. Annualized temperature trends (linear slope coefficients of **monthly mean minima** at urban and nonurban sites ($^{o}C\ yr^{-1}$), **1969-2006,** and their differences with significance

Month	Urban	Nonurban	Difference	Significance*
Jan	0.065	0.024	0.041	c
Feb	0.065	0.004	0.061	c
Mar	0.089	0.023	0.066	c
Apr	0.099	0.034	0.066	c
May	0.109	0.054	0.055	c
Jun	0.090	0.038	0.051	c
Jul	0.045	0.016	0.029	c
Aug	0.051	0.021	0.030	c
Sep	0.061	0.021	0.040	c
Oct	0.068	0.031	0.037	b
Nov	0.059	0.024	0.035	
Dec	0.018	-0.013	0.030	b
Annual	0.068	0.024	0.043	c

2 urban stations (Campbell Ave #28796, Tucson WFO #28815) & 4 nonurban stations (Anvil Rnch #20287, Cascabel #21330, Oracle 2SE #26119, Santa Rita Exp Rng #27593)

*Difference significant:
(a) at 0.05
(b) at 0.01
(c) at 0.001

Table 3. Annualized temperature trends (linear slope coefficients of **monthly mean minima** at urban and nonurban sites ($^{o}C\ yr^{-1}$), **1984-2005,** and their differences with significance

Month	Urban	Nonurban	Difference	Significance*
Jan	0.060	0.058	0.002	
Feb	0.031	-0.003	0.034	
Mar	0.053	0.000	0.053	b
Apr	-0.003	-0.081	0.077	c
May	0.030	0.024	0.006	
Jun	0.022	0.011	0.011	
Jul	0.074	0.038	0.036	
Aug	0.034	0.015	0.019	
Sep	0.097	0.071	0.026	
Oct	0.009	-0.024	0.034	
Nov	0.034	0.025	0.008	
Dec	-0.001	-0.010	0.009	
Annual	0.036	0.008	0.028	

2 urban stations (Campbell Ave #28796, Tucson WFO #28815) & 4 nonurban stations (Anvil Rnch #20287, Cascabel #21330, Oracle 2SE #26119, Santa Rita Exp Rng #27593)

*Difference significant:
(a) at 0.05
(b) at 0.01
(c) at 0.001

While T_{max} is not an indicator of urban heat island per se, it can have an important effect on vegetative water demand. Table 4 and Figure 7 show T_{max} trends for the full 1969-2006 meteorological period of record. However, the real implications of changing climate for outdoor water demand is expressed in reference evapotranspiration (and the degree to which irrigation watering supplies plants with sufficient moisture so that actual ET is close to reference ET).

Table 4. Annualized temperature trends (linear slope coefficients of **monthly mean maxima** at urban and nonurban sites ($^{o}C\ yr^{-1}$), **1969-2006,** and their differences with significance

Month	Urban	Nonurban	Difference	Significance*
Jan	0.022	0.003	0.019	b
Feb	-0.024	-0.039	0.016	b
Mar	0.037	0.009	0.027	c
Apr	0.016	0.002	0.015	b
May	0.054	0.049	0.005	
Jun	0.013	-0.002	0.015	a
Jul	-0.003	-0.006	0.003	
Aug	-0.023	-0.034	0.011	
Sep	0.015	0.003	0.013	a
Oct	0.037	0.022	0.016	b
Nov	0.007	-0.022	0.029	b
Dec	-0.015	-0.042	0.027	c
Annual	0.010	-0.003	0.013	b

2 urban stations (Campbell Ave #28796, Tucson WFO #28815) & 4 nonurban stations (Anvil Rnch #20287, Cascabel #21330, Oracle 2SE #26119, Santa Rita Exp Rng #27593)

*Difference significant:
(a) at 0.05
(b) at 0.01
(c) at 0.001

Additional analyses were undertaken of reference evapotranspiration (ET_{ref}) trends over time for one of the same urban stations (Campbell Ave. #28796) and for the closest nonurban station (Safford) for which ET_{ref} data were available. These results are presented in Table 5 and Figure 8.

The ET_{ref} results in general lack statistical significance, with the exception of the months of August and September, which show declining trends for urban – nonurban ET_{ref}, and December, which shows a modestly positive difference with increasing urban ET_{ref}. Given these indeterminate ET_{ref} results, the positive trends in T_{min} discussed above and as measured by our Landsat TM analysis would appear to have marginal effect on evapotranspiration and thereby on outdoor residential irrigation demand.

Figure 9 summarizes the results of the water supply data analysis. We ran regressions of total annual water supply by section and derived annual outdoor water by section on the following independent variables: year, annual precipitation, and annual ET_{ref}. Additionally we ran regressions of April-May-June (AMJ) water supply by section and derived AMJ outdoor water by section on the following independent variables: year, AMJ precipitation, and AMJ ET_{ref}. As expected, the sections with high NDVI exhibited the most statistically significant results for AMJ total water vs. AMJ ET_{ref}. In general the regression results were weaker for derived outdoor water than for total water supply, with one set of notable exceptions: annual derived outdoor

water was negatively correlated with total annual precipitation. These results are counter-intuitive, implying that decisions to water landscape vegetation are based on users' perceptions of combined rainfall amounts. Further assessment will be conducted for the project outputs listed below.

Table 5. Annualized reference evapotranspiration trends (linear slope coefficients of **average daily ET_{ref}** at urban and non-urban sites (mm d^{-1} yr^{-1}), **1987-2007,** and their differences with significance

Month	Urban	Non-Urban	Difference	Significance*
Jan	0.030	0.038	-0.008	
Feb	0.022	0.042	-0.020	
Mar	0.037	0.036	0.001	
Apr	0.026	0.028	-0.002	
May	0.028	0.026	0.002	
Jun	-0.043	-0.042	-0.002	
Jul	-0.040	-0.042	0.002	
Aug	-0.034	-0.019	-0.014	b
Sep	-0.061	-0.045	-0.016	b
Oct	-0.028	-0.019	-0.009	
Nov	-0.012	-0.018	0.006	
Dec	0.032	0.029	0.002	b
Annual	-0.004	0.001	-0.005	

1 urban station (Campbell Ave #28796)
& 1 non-urban station (Safford #27390)

(a) at 0.05
(b) at 0.01
(c) at 0.001

In sum, the project has satisfactorily met objectives 1 and 3. As observed by the review panel when the award was made, objective 2 is particularly challenging. We have demonstrated that vegetation profile (high, low, or increasing NDVI) is linked to water demand. However, future projections of water demand were not attempted here. In order to realistically reflect water users' practices, demand forecasting must account for water pricing, perceptions of and responses to scarcity, and policy initiatives promoting (or inhibiting) water conservation.

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Figures

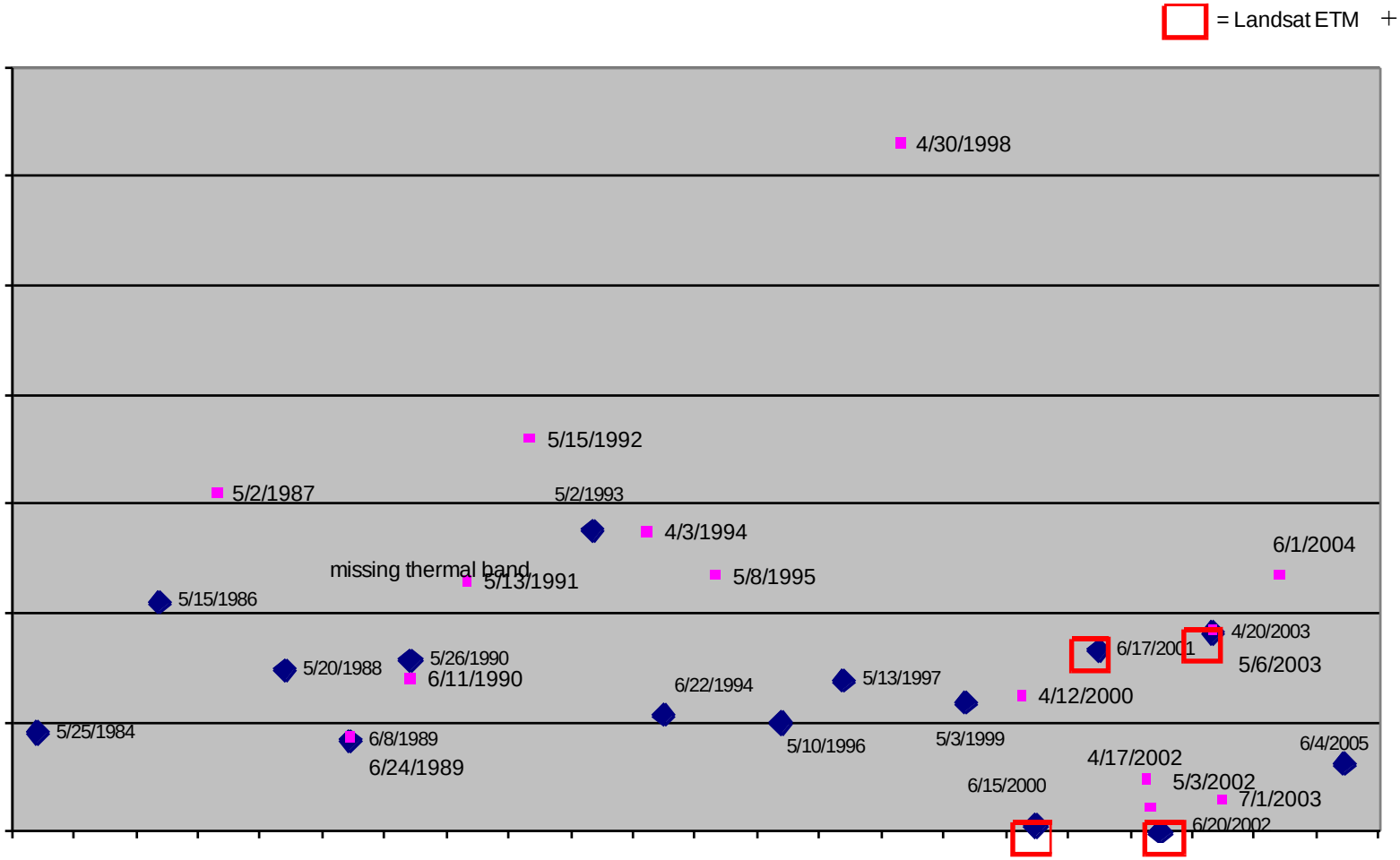

Figure 1. Landsat TM Image Acquisition Dates and 90-day Antecedent Precipitation

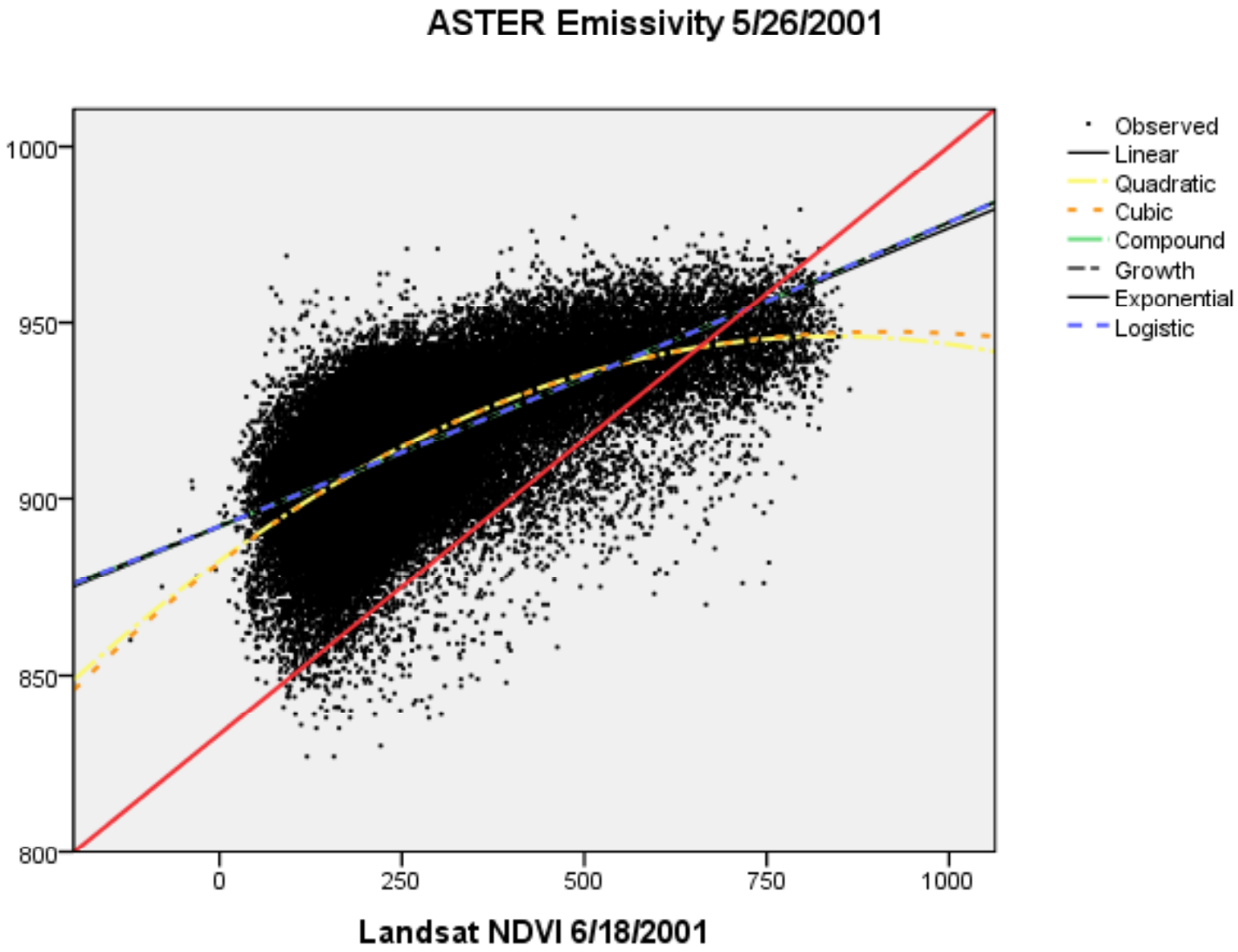

Figure 2. NDVI (Landsat) to Emissivity (ASTER) Correlation

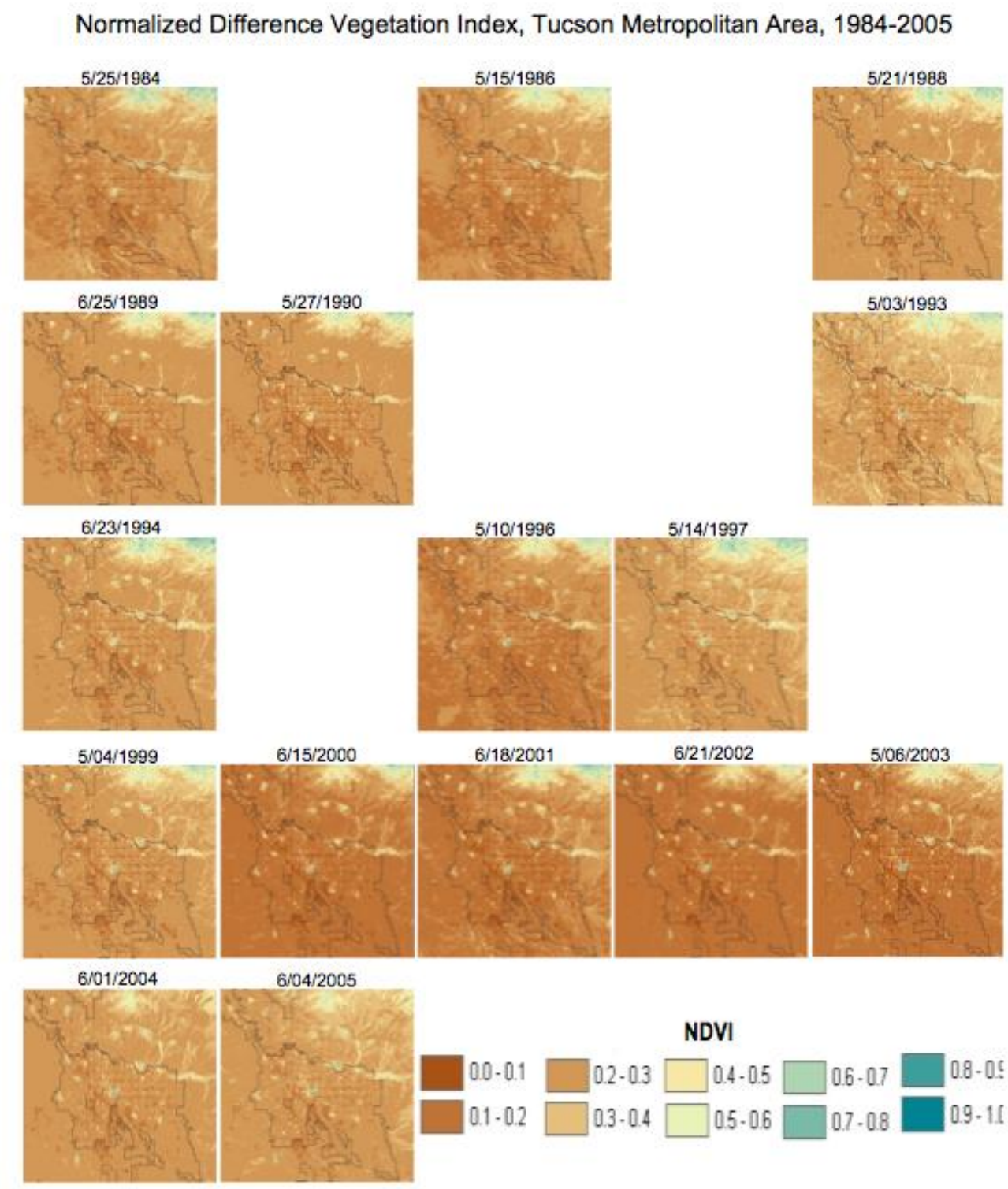

Figure 3. Normalized Difference Vegetation Index, Tucson Metropolitan Area, 1984-2005
Gaps in the semi-decadal grid above are years when no Landsat image was available.

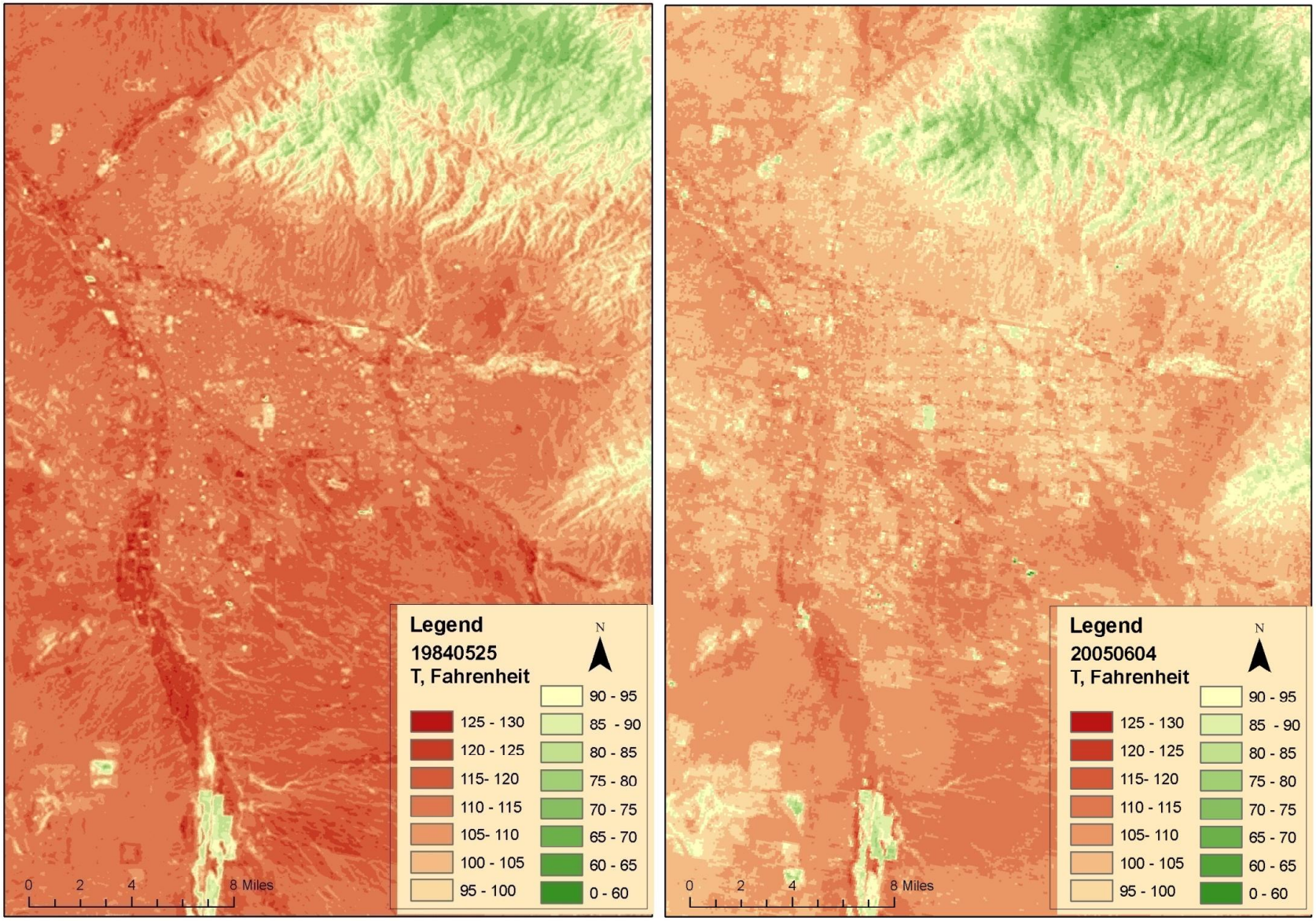

Figure 4. Kinetic Temperature (a) May 25, 1984 and (b) June 4, 2005

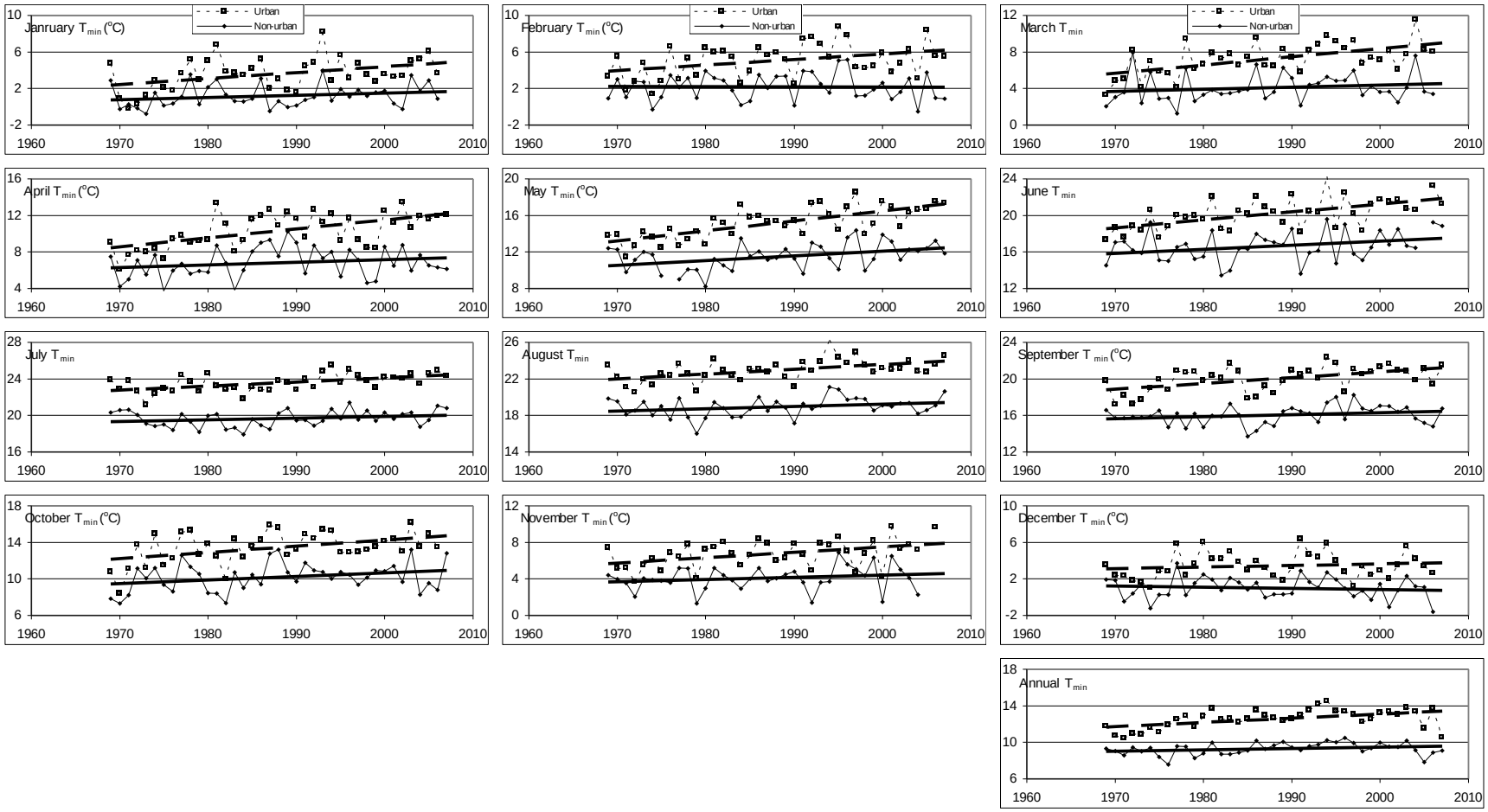

Figure 5. Urban and Nonurban **Minimum Temperature (°C), 1969-2006**, Corresponding to Meteorological Period of Record

These data indicate the rate of urban warming caused by urban heat island is more rapid than non-urban warming; however, the rate of urban warming over 1969-2006 is lower than that found by Comrie 2000 for 1969-1998 for all months except November and December. Due to the extended data period, our 1969-2006 time series regressions have greater statistical significance and are considered more robust than the 1969-1998 regressions.

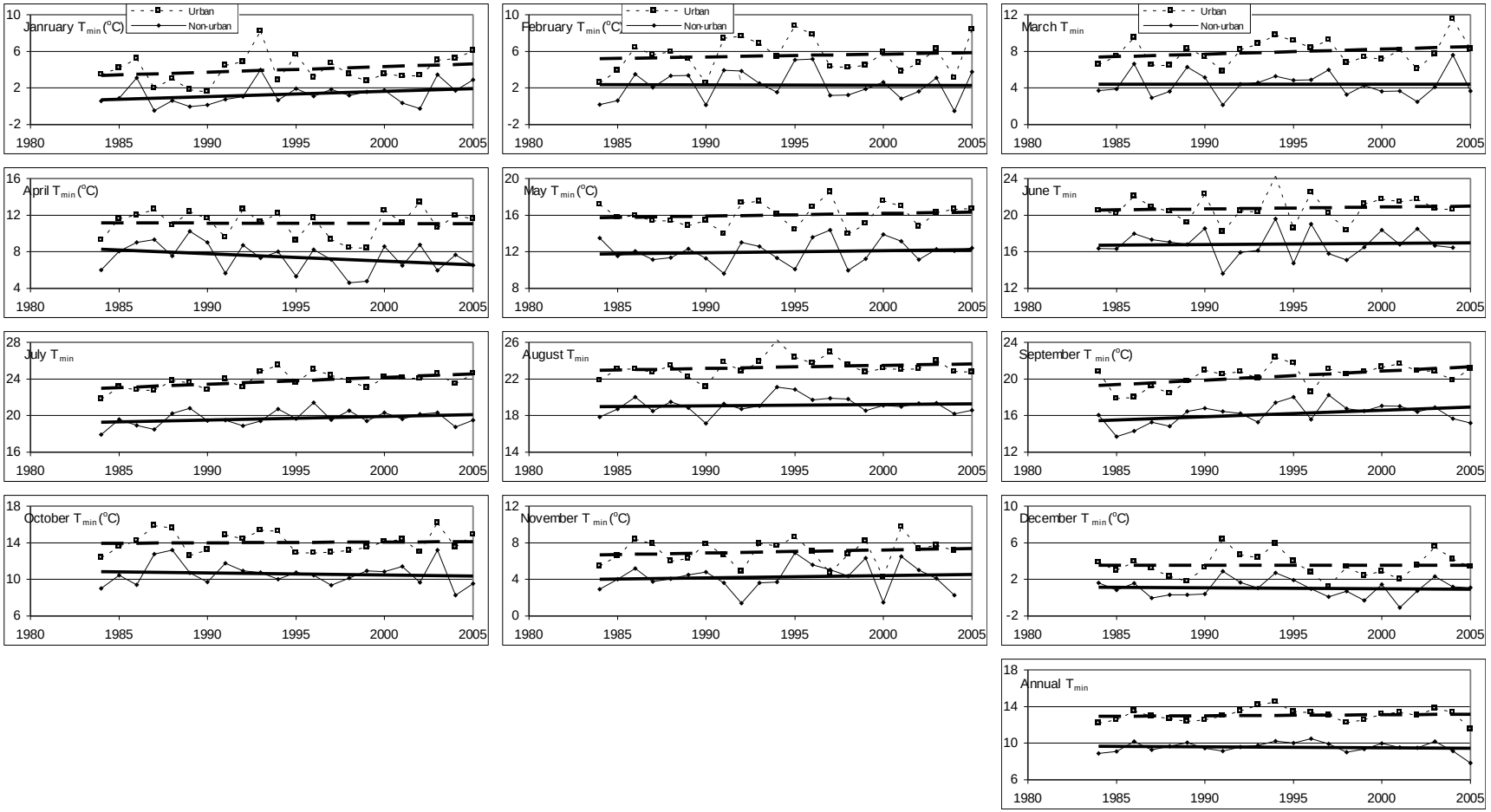

Figure 6. Urban and Nonurban **Minimum Temperature (°C), 1984-2005**, Corresponding to Landsat Period of Record

While the rate of urban warming for the 1984-2005 period of Landsat record appears to be lower than the 1969-2006 rate of warming, due to the reduced number of years, only the March and April regressions are statistically significant (at 0.01 and 0.001 respectively). However, it should be noted that, compared to other months, March and April have the highest annual rates of urban-nonurban difference for this 1984-2005 period.

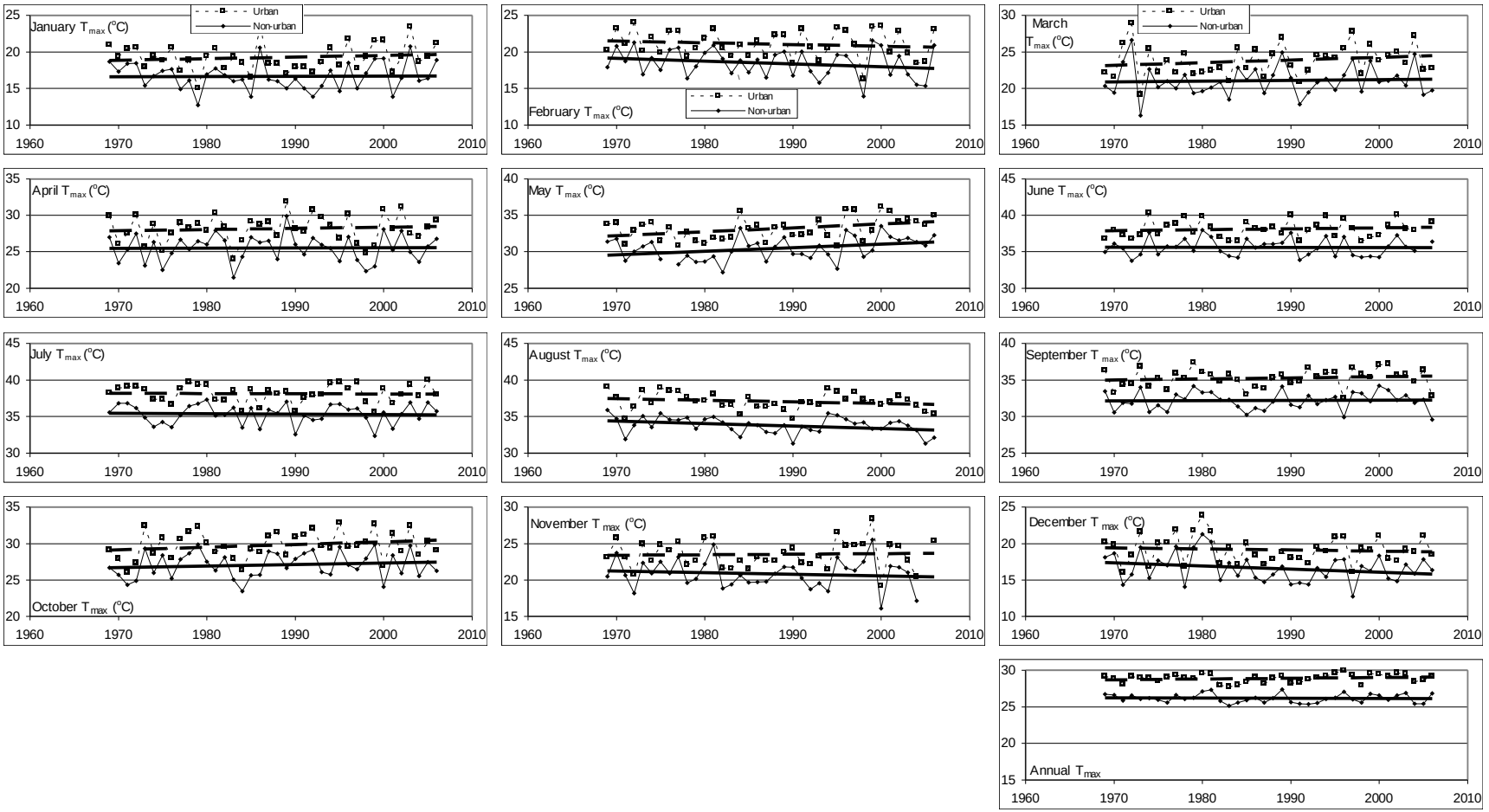

Figure 7. Urban and Nonurban **Maximum Temperature (°C), 1969-2006**, Corresponding to Meteorological Period of Record

The rates of urban - nonurban T_{max} increases are lower than for T_{min}. However, the urban - nonurban differences are most pronounced for March and December (each 0.027 °C/year, significant at $p < 0.001$), which account for the start and end of the vegetative growing season.

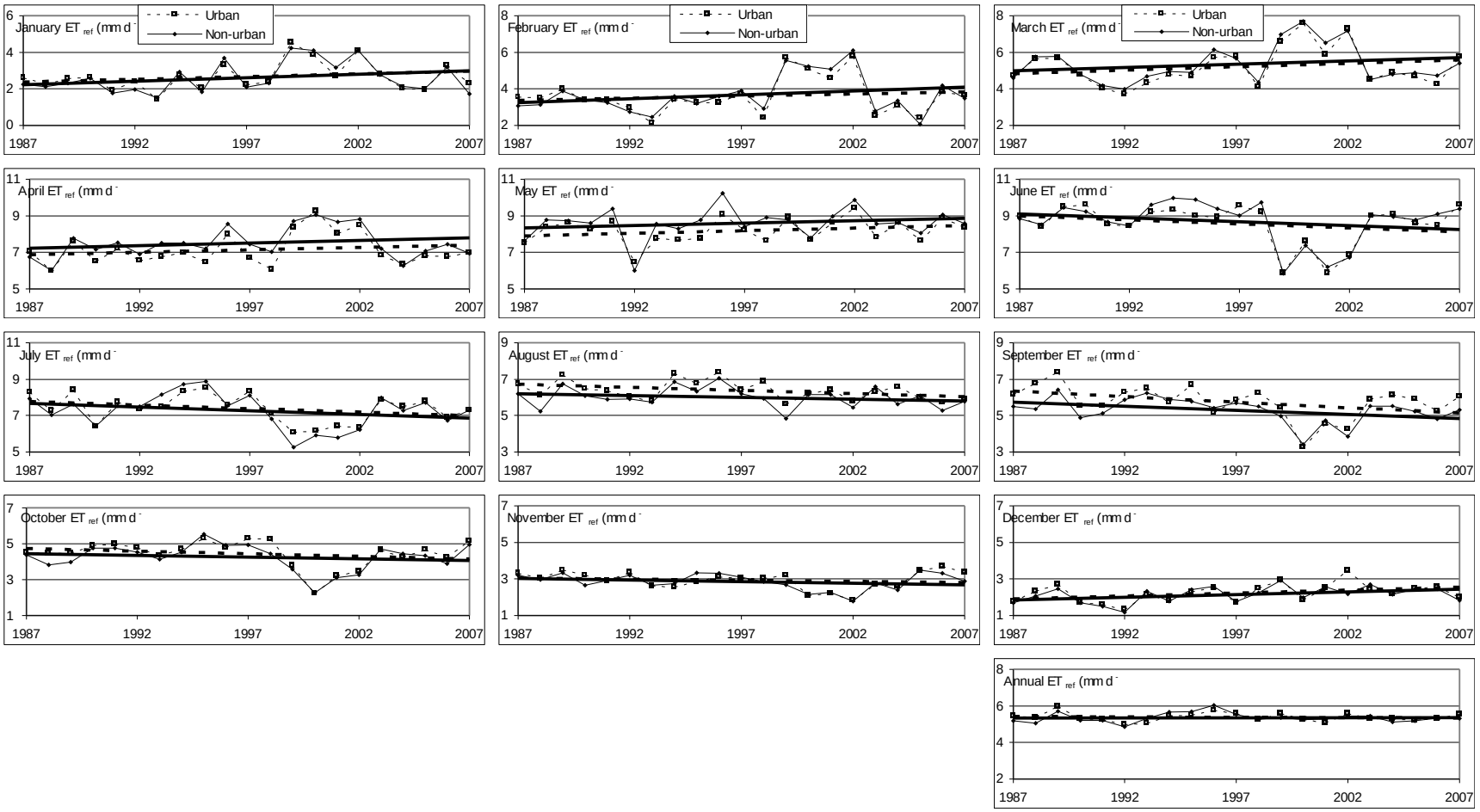

Figure 8. Urban and Nonurban Reference Evapotranspiration (mm/day), 1987-2007, Corresponding to AZMET Period of Record

(Urban ET_{ref} follows nonurban trends very closely. Both urban and nonurban stations show December – May ET_{ref} increases over the 1987-2007, with decreases for June – November; however, the results are only statistically significant at $p < 0.05$ for the months of August, September, and December. The net result of virtually zero annual change is not statistically significant.)

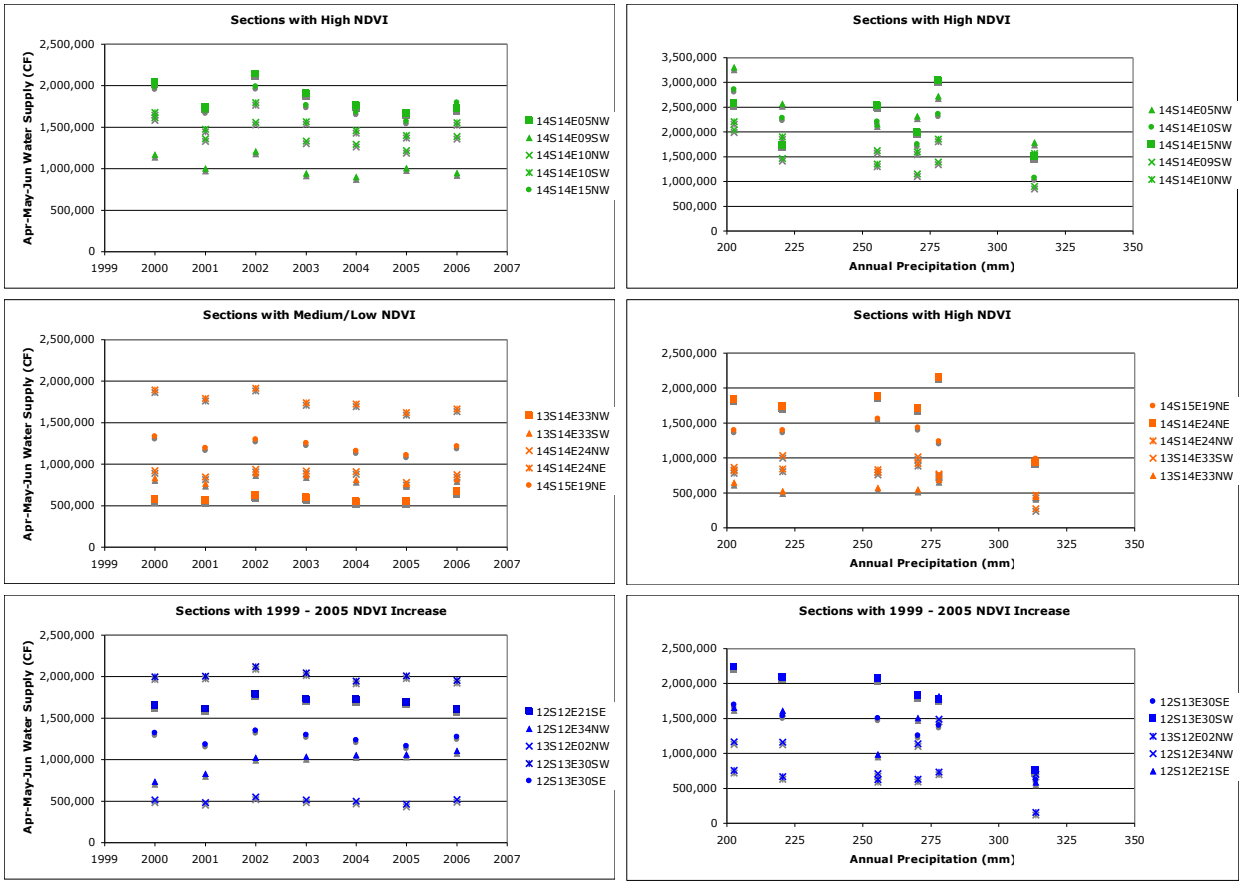

Figure 9. Water Supply (Cubic Feet by Selected Section), 2000-2006

Meta-Analysis of Rangeland Water-Yield Experiments for the Southwestern U.S.

Basic Information

Title:	Meta-Analysis of Rangeland Water-Yield Experiments for the Southwestern U.S.
Project Number:	2008AZ267B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	7
Research Category:	Climate and Hydrologic Processes
Focus Category:	Methods, Management and Planning, Water Quantity
Descriptors:	meta-analysis, statistics, sediment, rangeland, water yield, experiments, southwestern U.S., watershed, semi-arid
Principal Investigators:	Ed de Steiguer, Steven Archer

Publication

A. Problem and Research Objectives:

The purpose of the project was to gain an improved understanding of the effects of rangeland management activities on water-yield. Our methodology relied upon meta-analysis, a form of statistical research synthesis that has been used in several fields of science such as medicine, psychology and education. This study used data from published watershed and rangeland experiments to estimate a meta-regression model. The regression model, by statistically combining the results from many field experiments, facilitates a more complete understanding of the response of semi-arid lands to treatments and conditions than would individual experiments. Furthermore, the research is cost-effective because it makes use of existing research.

The research objectives were:

1. to collect a number of published experiments representing numerous scientific observations on the subject of rangeland water-yield experiments in the southwestern United States.

2. to summarize and code these studies in terms of water yield and other, resource outputs, experimental treatments, site-related variables, and factors related to experimental design.

3. to develop and estimate a series of meta-analysis regression models in order to synthesize and extend the results of these several experiments across a diversity of rangeland water management situations.

B. Methodology:

Objective 1. The electronic data base, *Web of Science*, was used to locate suitable studies for statistical synthesis. In selecting articles, emphasis initially was placed upon studies that have attempted to measure water yield, sediment loading, and nutrient loading under various land management treatments. The objective was to find published studies rather than original data sets. The published studies were categorized into a matrix by vegetation type and by the type of hydrologic response measured in an attempt to identify the experiments that would likely serve as a suitable data set.

Objective 2. Studies identified as a part of Objective #1 were coded according to the hydrologic response variable, the experimental treatments, and the site-related characteristics. Each of these was treated as an observation. A single study could contain more than one observation (e.g., the control vs. the experimental trial). The study results were summarized in a spreadsheet that served as the data base for estimation of the meta-analysis regression models under objective #3.

Objective 3. This objective deals with the statistical analysis. With the meta-analysis, data from Objective #2 were used to estimate regression models using SAS® statistical software. The general form of the meta-analysis model was as follows:

$$y_{j,i} = f(T_{k,l}, C_{l,i})$$

where:

$y_{j,i}$ = the j^{th} hydrologic response (e.g., water yield, sedimentation, runoff, etc.) for the i^{th} study,

$T_{k,i}$ = the $k^{th\ land}$ treatment (e.g., fire, herbicides, simulated rainfall, etc.) for the i^{th} study,

$C_{l,i}$ = the l^{th} site characteristic (e.g., slope, soil type, vegetation type, etc.) for the i^{th} study.

The model was estimated as a general linear model of the following form:

$$y = X\hat{\beta} + \varepsilon$$

where:

y = a vector of observed experimental responses

X = a matrix of observed independent variables; these may be either continuous data or dummy variables to represent states or conditions (such as 1 = mesquite type, 0 = otherwise).

$\hat{\beta}$ = a vector of estimated regression coefficients

ε = a vector of random error terms which is unobservable

From the meta-analysis**,** it was the estimated regression coefficients which are of interest to this study. These coefficients measure the contribution to the dependent variable due to a one-unit change in the independent variable on the assumption that all other independent variables are held constant:

$$\frac{\partial Y_{j,i}}{\partial X_i}$$

The partial regression coefficients with meta-analysis represent the synthesized, quantified results from many experiments. Thus, this research will provide the technical coefficients useful for the development of semi-arid land decision support systems, optimization models and other forms of management decision tools.

C. Principal Findings and Significance:

The *Web of Science* literature search results (Table 1) presented a number of options with respect to the vegetation type and hydrologic response variable that could be analyzed. The researchers selected the published "sagebrush-sediment/runoff" literature set which consisted of 51 publications to possibly form a meta-analysis data set. Copies of these 51 publications were obtained, most in PDF format. After examination of these publications it was finally determined that 19 were suitable as candidate meta-analysis studies. The others were omitted from further consideration because they did not provide adequate quantitative data, or the reporting was not sufficiently lucid.

Table 1. Web of Science Literature Search					
Number of Hydrologic Experimental Publications for the Semi-arid Western U.S.					
	Hydrologic Response Variables:				
		sediment			
Vegetation type:	**water yield**	**runoff**	**streamflow**	**snowmelt**	**sum**
Ponderosa Pine	18	29	21	8	76
Pinyon Juniper	3	16	6	1	26
Mesquite	15	19	10	2	46
Sagebrush	35	**51**	5	18	109
Chaparral	7	7	10	0	24
Grassland	263	467	65	38	833
Rangeland	115	214	24	19	372
Shrub	137	271	26	55	489
sum	593	1074	167	141	

The 19 manuscripts retained for analysis were examined for their experimentally measured response variables. Those manuscripts with sediment runoff measured as "volume per unit area" (e.g., kg/ha) were more prevalent and thus providing a better opportunity for constructing a suitable data set. This resulted in the retention of six manuscripts which, due to their multiple site x treatment experimental replications, yielded 165 suitable observations.

The typical experiments consisted of: 1) a land treatment involving clearing of vegetation by chemical, fire or mechanical means, vs. an experimental control (i.e., no land treatment); and 2) the application of simulated rainfall to the experiment and the control plot at a specified rate for a specified duration. Total rainfall on the experimental site was calculated in mm. For each site x treatment replication, typically there were data for the site characteristic, most typically soil type and slope; these were also recorded.

For each of the 165 experimental observations, the land treatments were coded into just two categories: 1) control, and 2) treated. The latter category included a wide variety of treatments that were difficult to further sub-categorize because of the lack of precise, quantitative definitions of the treatments in the manuscripts. Furthermore, at the present time the researchers are still attempting to code the soil and slope descriptors.

Hence the reduced regression model was actually estimated as follows:

$$y_{k,i} = f(T_{k,l}, R_{k,i})$$

where:

y = sediment yielded, in kg/ha, for the k^{th} treatment and i^{th} observation

$T_{k,i}$ = the k^{th} treatment for the i^{th} observation; where 1= treated plot, 0= control plot.

$R_{k,i}$ = the total simulated rainfall, in mm, for the k^{th} treatment, for the i^{th} observation.

The *a priori* expectation was that the estimated signs of both T and R will be positive indicating that disturbance of the soil and rainfall will increase sedimentation.

The preliminary statistical results obtained thus far (Table 2), indicate that the two independent variables, land treatment and rainfall, both had positive signs and both were significantly different that zero. Thus, the results indicate that meta-analysis has been able to obtain the *a priori* expected results. The model R-square, at .13, is relatively low; however, recall that the soil type and slope have not yet been coded into the regression model.

Table 2. Model summary

R	R Square	Adjusted R Square		Std. Error of the estimate
.36	.13	.12		1750.1
Regression model parameters:				
Predictors	B_i	Standard error	t value	p value
Treatment/control	765.9	289.3	2.6	.009
Amount of Rainfall	23.5	5.6	4.2	.000

From the findings it appears as though meta-analysis of extant rangeland experiments is possible and, furthermore, capable of providing statistically useful results. However, the study and the coding experience indicate that the meta-analysis results could possibly be significantly enhanced by more standardized experimental and publication protocols.

Lessons Learned: Extending the student/staff/faculty collaborative work model to the K-12 education

Basic Information

Title:	Lessons Learned: Extending the student/staff/faculty collaborative work model to the K-12 education
Project Number:	2008AZ273B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	Arizona 7th
Research Category:	Not Applicable
Focus Category:	Conservation, Education, Management and Planning
Descriptors:	None
Principal Investigators:	James Joseph Riley, James Joseph Riley

Publication

2. Descriptive Information

A. Problem and Research Objectives

The purpose of this study is to extend the UA student/faculty/staff collaborative model to K-12 schools in the Tucson area and to construct an educational rainwater harvesting demonstration at the Cochise Residence Hall and other off-campus sites. The project will provide training and experiential education for elementary, undergraduate, and graduate students through the design and implementation of rainwater harvesting systems and to disseminate both practical skills and a working knowledge of regional water issues to the greater Tucson community. The proposed projects will further define the UA's role in the community as a learning laboratory for sustainability and water conservation.

B. Methodology

- close observation, mapping, calculation, and monitoring of water quantity and surface flow patterns at Cochise Residence Hall;
- close observation, mapping, calculation, and monitoring of water quantity and surface flow patterns at Brichta Elementary School and Kino Learning Center sites;
- design and teaching of elementary school curricula for rainwater harvesting and water conservation;
- design and implementation of educational rainwater harvesting system surrounding Cochise Residence Hall;
- mulching and planting of native vegetation mimicking that found along ephemeral streams of the Sonoran Desert;
- projection of most ideal methods for redesign of sidewalk and roadway features to facilitate water flow into catchment basins, swales, and planted beds;
- design and implementation of educational rainwater harvesting system along with Brichta Elementary School and Kino Learning Center students, teachers, staff and parents;
- design and implementation of passive and water harvesting projects at Biosphere 2 to serve as demonstration of appropriate water management and conservation for arid lands.

C. Principal Findings and Significance

Activities supported by this grant involved projects developed by students in the Spring 2008 Water Harvesting class. Projects included on-campus passive water harvesting; active and passive water harvesting at two K-12 schools, and passive and active water harvesting at Biosphere 2 (now operated by The University of Arizona). A brief summary of the accomplishments is given below:

<u>Campus Water Harvesting - Cochise Hall</u>

By far, the most student working hours were devoted to modification of the grounds surrounding Cochise Residence Hall on the UA campus. Runoff modifications were implemented at three primary locations:

1) Grounds near northwest corner of building

Water from the roof used to run into a gutter system via perforated roof tiles along edges of the building. When original tiles were replaced, they were not perforated, allowing water to bypass the original drainage system and fall close to the building footings. One of these sites, identified by the Facilities Management Grounds staff, was at the NW corner of the building where water accumulated near the building and sometimes seeped into the building.

A passive water harvesting basin, constructed near the NW corner to catch water from the building, was designed to keep water away from the building. It was planted with grasses and lined with rocks. The overflow was directed parallel to the west side of the building, but away from the building, so that it also collects water falling from the roof and directs it to a small basin in the SW corner which, in turn, overflows to the parking lot. Basins and channels were lined with river rock to minimize erosion.

2) South Courtyard

In the south courtyard, rainfall roof runoff collected along the east and west walls of the courtyard. These areas were lowered slightly away from the building and lined with river rock. Overflows to the south panel were constructed in several locations to reduce pooling of water near the building walls. Not all planned modifications were implemented, for example lowering grassed panels to facilitate more efficient runoff.

3) Landscape panel south of building

The biggest challenge and the largest portion of time was spent constructing several passive water harvesting basins promoting infiltration of runoff from the courtyard and the parking lot located to the west and southwest of the building. The area is a utility corridor and hosted bicycles racks. The Hall residents complained that when it rained the area became a muddy swamp leading to tracking mud into the building and making access to bicycles difficult. Bicycle racks were relocated to the courtyard and gravel was placed over the entire area outside the harvesting basins. The deep water-harvesting basins were lined with Coronado Brown boulders and planted with a range of plants, with riparian plants in the lowest portions, and native desert plants on upper edges.

Now, the area is now completely passable after rains and Custodial Staff report less mud tracked into the building and reduced incidences of interior flooding. The table placed under the trees already on the site is used frequently throughout the day. The basin, into which the parking lot runoff drains, holds water from storms up to 1.5 inches, per the intended design. The captured water infiltrates into the ground within 24 hours avoiding mosquito propagation. Modifications have helped protect the integrity of the building and reduce runoff to East 4th Street.

Facilities Management's Grounds Shop provided the rocks used throughout the site and mechanical equipment for digging the rough versions of the south basins.

<u>Related campus developments</u>

The on-campus collaboration between students, faculty and staff continues to influence campus water management practices beyond the scope of the collaborative projects. Facilities Management used water harvesting to mitigate roof-drainage damage to the East wall of the Modern Languages Building. Downspouts were extended and directed to an excavated depression to keep water away from the building's foundation, which was less expensive than applying additional sealer to the foundation. The harvested roof-runoff provides supplemental irrigation to new landscape plantings.

<u>Water Harvesting at K-12 Schools</u>

1) Brichta Elementary School

The Brichta Elementary School is located near the intersection of West Speedway and Silverbell Rd. 5th-grade teacher, Ms. Katie Eddleman, envisioned a site planted with native plants used by students to study desert habitat. Ms. Eddleman solicited the assistance of restoration ecologists in the selection of

the plant palette. The UA students provided landscape design to take advantage of runoff from a temporary building and the roof of a shaded recreation structure. Water Harvesting-class students worked with parents, teachers, and 5th-grade students to implement the project. A wide range of participants attended several student-led workshops which led to project completion. The objective: developing a site that attracts native birds and pollinators and serves as a site for learning and relaxation. The objective was realized

In addition, UA students developed and presented modules on water harvesting, desert ecology, and plant-selection considerations to the 5th-grade class.

2) Kino Learning Center

The Kino Learning Center is located near the intersection of North 1st Avenue and East Orange Grove Rd. It is a private institution emphasizing "learning by doing."
School grounds were surveyed and entered into a GIS database, and plans for extension of existing gardens and landscape were developed by the School, with the assistance of UA students. The collaborative team reshaped terraces to improve water collection for fruit trees. Participants from the UA and the Kino Learning Center attended a workshop on construction of ferrocement cisterns from May 31-June 1, 2008, which proved to be an excellent opportunity for all to learn how to build cisterns out of ferrocement. The team developed a design for an active water harvesting plan for the main building. Collaboration between UA students and Kino Learning Center teachers, staff and students was enhanced by a $3,900 grant from the UA Water Sustainability Program. The grant enabled the installation of gutters and downspouts to harvest water from one half of the school's roof and direct it to passive and active water harvesting sites. Two ferrocement cisterns were constructed by students and staff of the Kino Learning Center.

Recent visits to the school show the cisterns are functioning as planned by improving landscaping and gardens in the areas. A new net house, constructed with rammed earth, is under construction near one of the downspouts and its water will be used for irrigation in the net house.

3) The K-12 Collaboration Experience

Over the years we have attempted to establish collaborative programs with K-12 schools in the Tucson area. Until this project, we never had the active partnership and commitment from the schools to bring one to fruition. Just as it is imperative that faculty, students and staff work together on water harvesting projects on the UA campus; similarly, it is necessary that teachers, parents, students, and maintenance staff work together at the K-12 institutions. We doubt that these projects would have been successful without that collaboration.

Grant McCormick and J.J. Riley are members of the Camp Cooper Advisory Committee, a collaborative effort between The University of Arizona College of Education and Tucson Unified School District. Camp Cooper, located in the Tucson Mountains foothills, is operated by TUSD for environmental and ecological training for TUSD and other K-12 schools in the Tucson area. It has heavily utilized field sites, laboratories, and over-night accommodations for K-12 students. The Advisory Committee assist in development of the site to provide education for students, teachers and staff of local school districts so that they can include concepts such as water harvesting and solar energy utilization at their schools and in their homes. Education conducted at Camp Cooper will facilitate further cooperation between UA Water Harvesting class students and other Tucson area K-12 institutions.

<u>Off-campus Water Harvesting</u>

1) Biosphere 2 Casita Demonstration

Working with the Biosphere 2 staff, a team of UA students in the Water Harvesting class developed a water harvesting plan for one of the 30 casitas at Biosphere 2 utilized by students, staff, and visitors. The design had passive and active water harvesting components. The selected casita, Casita 100, overlooks the Biosphere 2 building and is on the main tour route for visitors. As the active water

harvesting took longer to develop, UA students initiated the passive water harvesting features first by intercepting runoff up-grade from Casita 100 thereby protecting the active harvesting system site. On two occasions, local Americorps Youth Volunteers joined the UA students in development of the passive water harvesting features, consistent with our overall project goal of extending campus collaboration model to K-12 and the community. UA students designed an active water harvesting plan that included two 2000 gallon cisterns collecting water from Casita 100 roof with the harvested water being used to irrigate surrounding landscaping and flushing one toilet in Casita 100.

The UA Water Sustainability Program provided a supplemental grant to enable the implementation of the designed active water harvesting project. This phase of the project would not have been successfully completed without the direction and participation of the Biosphere 2 staff, especially their Sustainability Coordinator, Mr. Nate Allen, who completed the Water Harvesting Class in 2007.

2) Biosphere 2 site evaluation

Another student team studied the entire portion of the Biosphere 2 site under UA supervision to determine its potential for wide scale water harvesting. In preparation for this assignment, the team visited Kitt Peak National Observatory, SW of Tucson, as harvested rainwater is its only water source. The team considered harvesting water from main buildings, and selected the Energy Center as the first water-harvesting site because of its proximity to the project cooling towers, which represent the single largest water-use at Biosphere 2. The results of their study were presented to representatives of CDO, Inc., UA Biosphere 2 staff, and SAHRA staff, at the end of the semester. As of this writing, Biosphere 2 sustainability program is examining the potential for larger scale water harvesting.

Concluding Remarks

Two successful water harvesting projects with K-12 institutions were carried out with funding provided via this project. We found that university students were capable of interacting with elementary, middle school and high school students to successfully design and implement water harvesting projects. UA students and 5th-grade students at Brichta mutually benefited from the educational modules presented in the classroom. There is significant potential for developing similar projects directly, or via Camp Cooper.

While the intent of the project was to expand the model of student, faculty and staff collaboration at The University of Arizona with the local community, with emphasis on K-12 schools, we developed an improvement to the on-campus model, as well. We designed projects during the spring Water Harvesting class and began their implementation near the end of the spring semester, with work on most continuing into the summer.

Evaluation of this approach by the UA Surface Water Working Group, led to an improved model being developed. Under the new model, students in the 2009 Water Harvesting class conducted site surveys and developed designs for several projects. Reports prepared by student study teams will be evaluated by the Surface Water Working Group during the fall 2009 term, with the aim of selecting those considered most appropriate for on-campus implementation.

The Surface Water Working Group intends to “flesh-out” selected projects so that students enrolled in the Spring 2010 Water Harvesting class can implement them during the spring semester. Also, the Water Harvesting students will be tasked with identifying new projects, or modifying previous projects, so that they can be considered by the Surface Water Working Group during the fall of 2010.

This approach should assure that all facets of projects are reviewed and detailed, prior to implementation, by a wide range of experts familiar with campus programs, practices and design standards. It also provides opportunity for the students to participate in all phases of water-harvesting design and implementation, albeit on different projects, within the constraints of a one-semester class.

Database Creation: Transboundary San Pedro Valley Aquifer

Basic Information

Title:	Database Creation: Transboundary San Pedro Valley Aquifer
Project Number:	2008AZ346B
Start Date:	2/27/2009
End Date:	11/1/2009
Funding Source:	104B
Congressional District:	Arizona 7
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Management and Planning, Water Supply
Descriptors:	None
Principal Investigators:	Christopher A Scott

Publication

This project started February 27, 2009, and therefore has no progress to report.

Cooperative Agreement No. 08HQAG0058 Transboundary Aquifer Assessment Program

Basic Information

Title:	Cooperative Agreement No. 08HQAG0058 Transboundary Aquifer Assessment Program
Project Number:	2008AZ366S
Start Date:	3/17/2008
End Date:	3/16/2009
Funding Source:	Supplemental
Congressional District:	7
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Management and Planning, None
Descriptors:	
Principal Investigators:	Sharon Megdal, Christopher A Scott

Publication

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2. Megdal, Sharon B. 2008. “Front-Row View of Federal Water Lawmaking Shows Process Works – U.S. Mexico Transboundary Aquifer Assessment Act Pondered, Passed and Signed” (updated/revised version of 2007 column), in Norman, Laura M., Hirsch, Derrick D., and Ward, A. Wesley, eds., 2008, Proceedings of a USGS Workshop on facing tomorrow's challenges along the U.S.-Mexico border; monitoring, modeling, and forecasting change within the Arizona-Sonora transboundary watersheds: U.S Geological Survey Circular 1322, http://pubs.usgs.gov/circ/1322/.
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Introduction

Following protocol outlined by the Transboundary Aquifer Assessment Act (Public Law 109-448), a binational group of stakeholders led by the University of Arizona's Water Resources Research Center and the USGS-Tucson has worked to identify and prioritize assessment activities for the transboundary Santa Cruz River aquifer, with preliminary prioritization for the San Pedro River aquifer. A central goal of priority-setting meetings and field activities has been the continued engagement of this integrated cross-border stakeholder group. Participants represent municipal, state, federal, and binational agencies, as well as citizen groups and university researchers. In an effort to disseminate information on the TAAP and specifically the Arizona component's activities, the project has developed a public face by making presentations at public forums and conferences as outlined below.

Progress:

TAAP-AZ has created a database which aims to compile published and publicly available data related to the transboundary Santa Cruz River aquifer. This database, in Microsoft Access format, catalogues over 135 reference materials from various sources. The creation of such a database, in addition to providing a valuable source of information in respect to research on the Santa Cruz River, has also allowed TAAP-AZ to create strong networks among agencies and individuals that have contributed source material for database inclusion. A similar product for the transboundary San Pedro River aquifer is being initiated and will serve many of the same functions as the Santa Cruz database. This project is receiving additional support from a WRRC 104B grant. Hydrological groundwater models for different sections of each basin along with multiple studies related to the state of groundwater in the priority aquifers have been identified. Compilation of such sources (for the Santa Cruz database) has occurred both electronically, as well as in person at the following locations:

- Arizona Department of Water Resources; Nogales, Arizona
- Organismo Operador Municipal de Agua Potable, Alcantarillado y Saneamiento; Nogales, Sonora
- Comisión Estatal del Agua; Hermosillo, Sonora
- City of Nogales; Nogales, Arizona
- Bureau of Reclamation; Tucson, Arizona
- Comisión Nacional del Agua; Hermosillo, Sonora

Other activities in which TAAP-AZ is currently involved include:

- Participation in TAAP discussions alongside IBWC regarding data-sharing arrangements between US (for the states of Arizona, New Mexico, and Texas) and Mexico

- Analysis and delineation of institutional context of water management along and across the Arizona-Mexico border.

- Determination of bi-national modeling needs. This process is ongoing in conjunction with bi-national stakeholders.

TAAP-AZ continues to engage stakeholders and develop partnerships, primarily as a function of outreach and involvement in public information sharing activities. A workshop co-sponsored by ISARM and hosted by TAAP-AZ is being planned for early November 2009 with the goal of discussing shared

experiences in transboundary aquifer management at both regional and global levels. ISARM (Internationally Shared Aquifer Resources Management) is sponsored by the UNESCO International Hydrological Program (IHP). The USGS chairs the U.S. National Committee for participation in the IHP and makes recommendations for U.S. participation in IHP initiatives.

Future Activities:

As a result of preliminary priority-setting discussions, a variety of assessment activities have been outlined for inclusion in a draft work plan. A primary goal throughout potential activities (through FY13) is to work with partners on both sides of the border to create physically-based hydrologic models of Upper Santa Cruz and San Pedro River Basins that integrates surface-, ground-, and unsaturated-zone water. These hydrologic models will create and combine information to address a range of hydrologic questions and knowledge gaps, and decision-support for authorities in the U.S. and Mexico to plan for changes in population, climate, infrastructure, and water use (mining and agriculture). If finer scale models are needed, this model may be used to provide boundary conditions. Conversely, if finer scale models are developed concurrently to address local needs, the results can be incorporated into the larger model. A work plan draft for potential FY 2010 activities is currently being circulated among TAAP-AZ team members for comment and review. The work plan outlines study objectives for U.S.-side hydrological-study activities in the Santa Cruz and San Pedro areas. Mexican counterparts are also in the process of setting forth priorities which would fall under the larger TAAP-AZ work plan, but be focused specifically for activities within Mexico. This priority-setting is being done in direct consultation with core TAAP-AZ members.

Information Transfer Program Introduction

The WRRC has established itself as a primary link among the academic community; local, state and federal government; and the private sector for the exchange of water knowledge. Drawing on more than 45 years of experience, the WRRC provides timely and relevant information on water and related resource management issues statewide through its publications, functions, and research reports. Served communities include academic researchers and educators, water professionals, elected and appointed officials, students and the public. WRRC staff reaches out to these communities through presentations and lectures, service on boards, committees and panels, written articles and research activities.

Information Transfer

Basic Information

Title:	Information Transfer
Project Number:	2008AZ293B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	7
Research Category:	Not Applicable
Focus Category:	Water Supply, Law, Institutions, and Policy, Management and Planning
Descriptors:	None
Principal Investigators:	Sharon Megdal, Susanna Eden, Joe Gelt

Publication

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WRRC INFORMATION TRANSFER AND RELATED ACTIVITIES

The WRRC professional staff includes Sharon Megdal, Director; Kerry Schwartz, Associate Specialist, Director Arizona Project WET; Holly Hillburn, Arizona Make a Splash with Project WET Water Festival Program Coordinator; Jackie Moxley, Water Sustainability Program Coordinator, Kristine Uhlman, Area Assistant Agent, Natural Resources; Susanna Eden, Applied Research Coordinator, Joe Gelt, editor, Terry Sprouse, Senior Research Specialist, and Erin Westfall, Senior Research Specialist. Former Associate Director, Carl Bauer, continues his affiliation with the WRRC as a Faculty Associate.

Sharon Megdal is the C.W. and Modene Neely Endowed Professor for Excellence in Agriculture and Life Sciences. In addition to serving as WRRC Director, Prof. Megdal is the Water Sustainability Program Director. She is also a professor/ specialist in the UA Department of Agricultural and Resource Economics and the Department of Soil, Water and Environmental Science, and holds courtesy appointments with the UA Department of Public Administration and Policy and Department of Geography and Regional Development. She is also an adjunct professor for the UA Planning Degree Program and a member of the Arid Lands Resource Sciences Graduate Interdisciplinary Program. In addition, Dr. Megdal was elected in November 2008 to the Central Arizona Water Conservation District Board of Directors, which oversees the Central Arizona Project.

During the reporting period, Prof. Megdal gave numerous presentations on the topic of water management and planning, around the state. She also published articles, reports and commentary based on her water policy research. She spearheaded collaborative development of a bi-national research plan as part of the U.S.-Mexico Transboundary Aquifer Assessment Program and led a study on water conservation for environmental enhancement that has resulted in a proposal for a prototype "Conserve to Enhance" program generating considerable interest from conservation planners, municipalities and other water providers. She continues to teach her popular graduate-level water policy course and is the author of a water policy column for the WRRC's bi-monthly newsletter.

Prof. Megdal has encouraged the growth of international collaborations, supporting Graciela Schneier-Madanes, who has since become Deputy Director of a new joint research partnership between the UA and the French research agency CNRS, and hosting French students from AgroParisTech (Paris Institute of technology for life, food and environmental sciences). She also is leading the cooperative development of an international symposium and workshop planned for August 2009, with participation from Israeli, Palestinian and U.S. water policy experts and government officials.

As the Director of the Arizona Project WET (Water Education for Teachers) Program, **Kerry Schwartz** runs a comprehensive statewide water education program that is expanding to more school districts, teachers, and students each year and now reaches tens of thousands of individuals. As an Associate Specialist with the Department of Agricultural Education, she combines her knowledge of water resource management and hydrogeology with an ability to engage adults and students in learning. Ms. Schwartz administers grants from federal, state, county, city and public/private entities. In addition, she meets with an advisory council bi-monthly to guide the APW program. Ms. Schwartz participates in water education assessment and research projects and presented two of them at the North American Association of Environmental Education Conference in November 2008. As co-author of the new Arizona Conserve Water Educators' Guide, she is promoting the Guide by engaging students in real-world, community-based, conservation projects.

Holly Thomas Hilburn joined the WRRC in September 2008. As Program Coordinator for the Arizona Make a Splash with Project WET Water Festivals, she manages a program that supports local communities in organizing standards-driven water education events for fourth graders.

Jackie Moxley, Coordinator for the Water Sustainability Program (WSP), manages the major components of WSP that include: a competitive grants program, student fellowship program, recruitment and research initiative, and an education and outreach program. Ms. Moxley also coordinates the Water and Environmental Sustainability Program, which combines WSP and the Translational Environmental Research initiative into one reporting unit for the Arizona Board of Regents. She oversees staff in Maricopa County working with Cooperative Extension in Phoenix to help develop and deliver WSP

education and outreach programs to the state's largest population center. She was instrumental in organizing a workshop on reclaimed water use in collaboration with Cooperative Extension, as part of the series of WSP Education and Outreach workshops. She is involved with new content and updates to the WSP website and WRRC website on an ongoing basis. Development of new WSP promotional materials and publications and event planning are also part of her responsibilities.

As an Assistant Area Agent with Cooperative Extension, **Kristine Uhlman** is working with several Arizona counties on projects addressing water resources. She continues her role as the Arizona NEMO (Non-point Education for Municipal Officials www.ArizonaNEMO.org) Program Coordinator and is responsible for the development of watershed-based planning documents and educational outreach to land-use decision makers on non-point source pollution issues. Other projects include developing volunteer watershed and river monitoring programs for watershed partnerships across the state (NEMO Wet/Dry); development of a predictive MODFLOW groundwater model of groundwater resources in the central part of the State; isotope analysis of numerous water supply wells to determine groundwater age; an Arizona Water Institute (AWI) study on water reuse including mapping of riparian areas dependent on effluent flow from wastewater treatment facilities; a key-word searchable photo archive of historic photographs provided by the Bureau of Land Management; and a series of county-based water resource fact sheets for domestic well owners. In addition, for a contract by NEMO and the WRRC with the Natural Resources Conservation Service (NRCS), Ms. Uhlman is Principal Investigator on Rapid Watershed Assessments for ten of Arizona's seventeen watersheds. Working with campus faculty and County Extension Agents across the state, she has also developed a new outreach program addressing domestic well operation, maintenance, and water quality sampling. This new program coincides with the pending publication of Arizona Well Owners' Guide to Water Resources (Artiola and Uhlman) and the filming of a series of short videos on domestic wells.

Susanna Eden, Coordinator, Applied Research, is responsible for managing the WRRA Section 104(b) competitive grant program for the WRRC. She initiated an annual summer internship at the WRRC for students interested in writing about water for the general public. The first intern, Claire Landowski, a senior in Geosciences and Journalism, was selected by competition and worked at the WRRC on an Arroyo newsletter about water reuse. Dr. Eden also is working on a parallel initiative, an undergraduate writing contest, which will be implemented in 2009. She provided synthesis and reporting on WSP-funded research into the role of irrigation districts in the development of water markets and collaborated on an Arizona Water Institute research project to assess incentives for water reuse in Arizona. She also was a member of the planning committee for the 2009 annual conference and contributed to organization of the conference. In addition, she is completing her assessment of decision support activities for SAHRA (Sustainability of semi-Arid Hydrology and Riparian Areas) an National Science Foundation-Science and Technology Center.

Joe Gelt has a major role in the production of the two WRRC newsletters. He writes and edits the Arizona Water Resource newsletter and edits and co-authors the Arroyo newsletter. He prepared special coverage for two editions of the AWR: a four-page supplement reporting on WRRC's annual conference commemorating the 20th anniversary of the Arizona Department of Environmental Quality, and a special edition of the AWR noting the 50th anniversary of the University of Arizona's Water Resources Research Center. He also collaborated in developing a summer writing internship and statewide contest for student writers. In spring 2008, he received the UA College of Agriculture and Life Sciences Outstanding Staff Award. Mr. Gelt retired in January 2009, but he has returned half-time to continue editing and contributing to the WRRC newsletters.

Terry Sprouse, Senior Research Specialist, works with Project NEMO, coordinating activities in the Santa Cruz watershed and helping to produce Rapid Watershed Assessment Reports and Watershed-Based Plans for watersheds in Arizona. He collaborates on training watershed groups to do Wet/Dry Mapping of their watershed, and has helped in GIS mapping seminar presentations. Dr. Sprouse conducts research, and manages volunteers for the project "Status of Generation, Reuse, and Recharge of Treated Wastewater in Arizona." He is collecting data for a MODFLOW study of a groundwater basin in central

Arizona. Dr. Sprouse is also coordinating an update of the popular Arizona Water Map Poster and he manages the NEMO webpage.

Erin Westfall, Senior Research Specialist, applies her expertise in GIS and cartography on work for Arizona NEMO. Ms. Westfall creates cartographic products for reports and other published material, and assists with compiling and editing watershed-based plan reports for the Arizona Department of Environmental Quality (ADEQ). She is overseeing the development of a comprehensive database on effluent generation, discharge and reuse in Arizona for an Arizona Water Institute funded project. In addition, she carries out public outreach activities, including training volunteers for the Arizona NEMO Wet/Dry Mapping. She was co-author on several publications with Arizona NEMO Program Coordinator Kristine Uhlman.

Carl Bauer, the WRRC's Associate Director until July 2008, has become Director of Graduate Studies in the Department of Geography and Regional Development, where he is also Associate Professor. Dr. Bauer is the first Faculty Coordinator for the UA's Graduate Certificate in Water Policy, a new program whose implementation he has led since 2007 (http://gcwp.arizona.edu). Students began applying to the program in Fall 2007. There are currently 17 enrolled students and 3 have graduated. Dr. Bauer teaches courses on water, society and policy in the Geography Department, both undergraduate and graduate. He is a key academic contact for a visiting scholar from the French National Center of Scientific Research, Graciela Schneier Madanes, who is living in Tucson as part of the Center's research partnership with the UA.

A list of presentations by WRRC professional staff is appended.

WRRC PUBLICATIONS

Arizona Water Resource Newsletter

The Arizona Water Resource is a 12-page newsletter focusing on state and regional water issues. It is published 4 times per year and is sent free of charge to more than 2,700 people on the mailing list and distributed to more than 200 others via email. The newsletter has wide distribution; the majority of its readers are from Arizona, but it also is mailed to other states and foreign countries. The publication regularly includes a feature article, a guest view, news briefs, sections on special projects and on legislation and law. Each issue also includes a public policy column written by the WRRC Director, as well as announcements and publication notices. Most issues of the newsletter include a four-page special supplement inserted as a center fold.

Sponsors of the newsletters usually contribute material for the special supplements, recognizing the AWR as a primary vehicle for reaching their audience. This year major sponsors have been the U.S. Geological Survey, Arizona NEMO, The Nature Conservancy and the UA Water Sustainability Program. USGS has been prominent as a supporter of the WRRC newsletters contributing $2,563 toward publications this project year.

AWR Feature Articles 2008-2009:

- WRRC, Part of a 50-Year Legacy of Meeting Arizona Water Needs (March-April 2008)
- Drop 2 — End-of-The-Line Reservoir Salvages Colorado River Water (May-June 2008)
- How Much Virtual Water is Needed to Produce a Hamburger? (July-August 2008)
- Seagoing Desalination Plant Touts Environmental Benefits Arizona (September-October 2008)
- Well Owners Along Lower Colorado River Face Stricter Enforcement of Water Laws, (November December 2008)

AWR Supplements 2008-2009

- The Nature Conservancy, "The Ecological Implications of Verde River Flows."
- UA Water Sustainability Program, "UA Water Researchers Protect and Preserve State Water Resources: Technology and Research Initiative Fund supports research work"

- Arizona NEMO, "Arizona NEMO: Watershed Projects and Programs."
- United States Geological Survey, "Colorado River or Tributary Water—U.S. Geological Survey Update of the Accounting Surface Along the Lower Colorado River."

Arroyo Newsletter

The second annual edition of the revived Arroyo, a newsletter focusing on a single topic of timely interest to Arizona, was published Spring 2008. Titled "River Restoration: Arizona's Oft Neglected Waterways Get Overdue Attention," it described restoration projects implemented across Arizona and discussed restoration project issues relating to technical challenges, financing, collaboration, public participation, and continued water availability.

The task of the student awarded the WRRC summer writing internship in 2008 was to work on the upcoming edition of the Arroyo. A 2009 Arroyo on water reuse was developed through the teamwork of Intern Claire Landowski, Joe Gelt and Susanna Eden. A comprehensive look at the history, regulation, treatment, and uses of reclaimed water, the Arroyo describes new strategies for water reuse, along with the latest results of relevant university research projects, and explores public policy issues relating to treatment and distribution costs, incentives, and the protection of public health with reclaimed water for various uses, including potable reuse. Publication is planned for Spring 2009.

WRRC PRODUCTS

Arizona Water Map

The Arizona Water Map is being completely revised with up-to-date information and will be made available in 2009. This full-sized (31.5" X 41") color poster is suitable for framing and classroom use. An accompanying booklet providing in-depth explanations and supplemental information is planned for 2010.

Desert Landscaping CD

The Desert Landscaping CD continues to be offered by the WRRC on its website and at retail outlets. The updated version, released in 2005, features major improvements, including improved navigation and search capabilities and an expanded plant list.

Laypersons Guide

The Laypersons Guide to Arizona Water, published by WRRC in collaboration with the Water Education Foundation in 2007, is being distributed as the primary informational resource throughout Arizona. Aimed at a general audience, the Guide describes Arizona's water resources and their uses, the history of water development, water law and the management framework, and discusses the major water issues confronting the State. The Guide can be downloaded free of charge from the WRRC website or purchased in hardcopy form from WEF.

CONFERENCES, SEMINARS AND LECTURES

Annual Conference

The Conference, "The Importance of the Colorado River for Arizona's Future," was held June 24, 2008, at the Arizona Biltmore Resort & Spa. It provided a forum to discuss the past, present, and most importantly the future of the Colorado River. Luncheon speaker Robert Johnson, Bureau of Reclamation Commissioner, provided an overview of West-wide water challenges. More than 300 participants attended, including representatives from government, academia, non-profit groups, and private business along with interested citizens. The conference was organized in cooperation with the Central Arizona Project. Speakers' PowerPoint presentations are available on the WRRC web site: http://ag.arizona.edu/AZWATER/.

The 2009 Annual Conference "Best Practices for Stakeholder Engagement in Water Resources Planning," is planned for March 17 at the UA Student Union. The conference is being organized in collaboration with the Morris K. Udall Foundation and the Arizona Water Institute. Meant to develop a dialogue across a broad spectrum interests, the conference will include a poster session and three interactive workshops. Arizona NEMO and Arizona's Watershed Stewards Program are facilitating participation by watershed groups across the state.

Brown Bag Seminar Series

The WRRC's brown bag seminar series offers information and opportunities for two-way dialogue and for community-university interaction. The seminars focus on topics with broad appeal to academics from multiple disciplines, members of the water community and interested citizens. This year seminars attracted mixed audiences of about 35 people on average, roughly 40 percent from the campus and 60 percent from the wider community. Seminars in the period 2008-2009 are listed in the table below.

4/3/2008	Sharon Megdal, UA Joanna Bate, UA	Conserve to Enhance: Voluntary Municipal Water to Support Environmental Restoration
4/14/2008	Pam McRae-Williams, Univ. of Ballarat, Australia	Water in Drylands: Changes Brought About by Major Water Reform in Australia
8/29/2008	Steve Olsen, AMWUA Cliff Neal, CAGRD	Central Arizona Groundwater Replenishment District (CAGRD) Seminar
9/11/2008	Chuck Graff, Arizona Water Institute	The ABCs of ECs: Emerging Contaminants in the Environment
9/23/2008	Jonathan Mabry, City of Tucson	The Ancient Oasis: 4,000 Years of Agriculture and Irrigation in Tucson
10/6/2008	Peter Symes, Royal Botanical Gardens, Australia	Water Management Strategies for Heritage Landscapes- A Case Study, Australia
10/24/2008	Taylor Shipman, Montgomery & Assocs.	Predicting Direct Demand for CAP Water: A Spatial Economic Perspective
11/14/2008	Wally Wilson, Tucson Water	Tucson Water's Clearwater Program
12/8/2008	Sharon Megdal, UA James Callegary, USGS Chris Scott, UA Prescott Vandervoet, UA	The U.S Mexico Transboundary Aquifer Assessment Program
1/21/2009	Prof Mike Young, Univ. Of Adelaide	The Role of Governments and Markets in Water Reform: Lessons and Experience from Australia
1/21/2009	Bill Baker, Ellis & Baker, P.C Bill Van Allen, New Magma Jeff Silvertooth, UA Janick Artiola, UA	A First in Arizona: Reuse of Mine Water
2/11/2009	Nicole Ewing Gavin, City of Tucson Melaney Seacat, Pima County	City/County Water and Wastewater Study Phase 1 Draft Report, Presentation & Discussion

Other Seminars, Workshops and Events

In addition, the WRRC sponsored or co-sponsored meetings and lectures for students, the campus community and the public.

Symposium on Water Governance

The WRRC was a co-sponsor of the symposium, Water Governance: The Public-Private Debate held on February 4, 2009 on the UA campus. The event featured a number of distinguished speakers including Dir. Megdal, and it was well-attended by members of the university community.

Seminar on Colorado River Basin Water Management

The WRRC and Dept. of Civil Engineering and Engineering Mechanics co-sponsored a seminar by Dean Ernie Smerdon, Chair of the National Research Council Committee on the Scientific Bases of Colorado River Basin Water Management on February 13, 2009. Dean Smerdon presented a lecture titled "Colorado River Basin Water Management - Evaluating and Adjusting to Hydroclimatic Variability."

Reception for Sid Wilson at the WRRC

Friday, March 6, 2009, the WRRC hosted a reception to celebrate the more than 40 years of accomplishments by Sid Wilson, the General Manager of the Central Arizona Project, on the occasion of his retirement. Members of the Arizona water community and others joined us in honoring a state leader in water management and a long-time friend of the WRRC.

Guest Lecture for Geography and Regional Development

The WRRC provided sponsorship support for Stephen H. Schneider, the Melvin and Joan Lane Professor for Interdisciplinary Environmental Studies at Stanford University, to speak at the Southern Arizona Geographer's Association meeting, March 27, 2008

Geography and Regional Development Colloquium

The WRRC was a co-sponsor for the lecture given by Jennifer McKay, Director of the Centre for Comparative Water Policies and Law and professor of Business Law at the University of South Australia, "How drought has forced a new constitutional transition in Australian water law- the legal issues," on February 20, 2009, and to two talks by Caedmon Staddon, Department of Geography and Environmental Management, The University of the West of England: "Climate, Change, and Water" and "The Social Life of Water," April/1-2, 2008, as part of the Geography and Regional Development Colloquium series.

Special Seminar on the Central Arizona Water Replenishment District (CAGRD)

A special seminar at the WRRC was presented by Steve Olson, Executive Director, Arizona Municipal Water Users Association (AMWUA) and Cliff Neal, Manager, Central Arizona Groundwater Replenishment District (CAGRD) on Friday, August 29, 2008 from 10:00 to noon. The CAGRD is the organization charged with ensuring that expanding member cities and new developments in central Arizona will have enough water to supply their needs into the future. More than 50 people attended.

Water History Symposium

A symposium on water history of the Southwestern United States, presented at the Udall Center for Studies in Public Policy on March 19, 2008, was a cooperative effort by several UA campus units including the WRRC. The symposium brought together reports on a wide spectrum of topics by researchers who rarely share the same lectern.

WRRC WEB PRESENCE AND ELECTRONIC COMMUNICATIONS

The Internet is an effective outreach vehicle, and the WRRC endeavors to make effective and extensive use of our web site. The site has recently undergone redesign to update its look and improve its navigability. The new webpage takes advantage of software improvements to be more attractive, user-friendly, and easier to manage. In addition to WRRC news and events, the site carries AWR and Arroyo, as well as papers, presentations and links to many other water sites. Staff profiles and information about WRRC products are also easily accessible.

With the support of 104(b) Information Transfer Program funds, the WRRC was able to hire a web support specialist for work at the WRRC in FY2009. He will be continuing to implement improvements to the WRRC web site and design enhancements to make it even more attractive and efficient.

Video Introduction to the WRRC

The WRRC took advantage of an opportunity provided by Water TV to create a five-minute introductory video, "Keeping Water Knowledge Flowing, Water Resources Research Center, University of Arizona." The video describes the WRRC and its collaborations with Arizona's water stakeholders in fulfillment of its mission to deliver highly relevant water management and policy research, education, and information outreach. The video was originally shown at the American Water Resources Association annual conference in New Orleans, November 2008, and subsequently made available for viewing on the WRRC website.

Electronic Mailing Lists

Another component of WRRC information transfer is to keep researchers of the three Arizona universities apprized of funding opportunities and upcoming events. The WRRC maintains several targeted email lists that are used to distribute announcements and notices received from a wide range of other institutions and organizations to appropriate recipients.

ASSOCIATED PROGRAMS

The WRRC houses several programs with important university and statewide missions in water research, education and information transfer. WRRC staff members have major responsibility for directing and coordinating these programs and the WRRC provides them administrative support. The association of these programs has a synergistic effect, greatly enhancing the reach and impact of each.

THE UA WATER SUSTAINABILITY PROGRAM

WRRC is one of five UA water centers that make up the Water Sustainability Program (WSP). The program grew to five water centers with the addition of the Superfund Basic Research Program in early 2008. Now in its eighth year, this campus-wide collaboration of scientists and educators has made significant contributions to the body of research, education and outreach applied to Arizona water resources issues. Funded through the state Technology and Research Initiative Fund (TRIF) the WSP will allocate approximately $3 million/year over the next three years to campus water projects and programs. WRRC continues to play a pivotal role in implementing, developing, and managing program components.

Co-Sponsored Forums and Workshops

In the spring, a joint workshop on reclaimed water use was held by the WSP Education & Outreach Committee and Cooperative Extension, with support from USDA and Global Water, as part of a series of workshops to inform water managers and decision makers. Accredited continuing education units are offered to participants.

Competitive Grants

A key component of the WSP is the competitive grants program. Each year approximately $1 million is allocated to UA faculty and staff to fund projects relevant to critical Arizona water issues. In 2008, 18 new projects were selected through a panel review process and four projects were granted continuation of funding for the next cycle beginning July 1, 2008. More information on the grants can be found at www.uawater.arizona.edu under the Programs menu. New projects selected in the review

process this spring that involve WRRC staff and/or are hosted by the WRRC for 2008/09 include the following:

1. Ground Water Age Dating for Water Budget Development in the Show Low Watershed, Navajo County, AZ. $4,800 – 1 year. Kristine Uhlman, Water Resources Research Center, Chris Eastoe, Dept of Geosciences, and Steve Campbell, Navajo County, Cooperative Extension. Partners: Arizona NEMO (Nonpoint Education for Municipal Officials), Arizona Department of Water Resources and Show Low Creek Watershed Enhancement Partnership.
2. Science Education That Makes a Difference - through Inspired Teacher Leaders. $34,479 – 1 year. Kerry Schwartz, Water Resources Research Center. Partners: ASU Polytechnic Science Education Program, and Arizona Foundation for Resource Education.
3. Yuma Desalting Operations, Water Quality and Vegetation Distribution in the Cienega de Santa Clara. $30,895 – 1 year. Karl Flessa, Dept of Geosciences. Partners: Central Arizona Project and Centro de Investigación en Alimentación y Desarollo (CIAD).
4. Optimum and Minimum Irrigation Requirements of Landscape Trees. $20,959 – 1 year. Ursula Schuch, Dept of Plant Science, Ed Martin, Maricopa Ag Center and Rick Gibson, Pinal County, Cooperative Extension. Partners: Arizona Landscape Contractor's Association, Pinal County Master Gardeners and the City of Maricopa.

One multi-year project involving WRRC staff received continued funding: Estimating Water Use: Monitoring Rural Domestic Wells with Low-cost, Near-real Time Water Metering. $58,970 – 2 years. Susan Pater, Kim McReynolds, Cado Daily, Cochise County Cooperative Extension, Gary Woodard and Ramon Vazquez, SAHRA, Dept of Hydrology & Water Resources, Sharon Megdal and Susanna Eden, Water Resources Research Center. Partners: Cochise County and Badger Meters.

Projects finalized this year, related to WRRC, include:

1. San Pedro River Volunteer Monitoring, Community Watershed Alliance, Cochise County, AZ. $4,895 – 1 year. Kristine Uhlman, Water Resources Research Center and Phil Guertin, School of Natural Resources.
2. 'Paper Water' Demystified: An Economic Evaluation of CAGRD Spatial Dynamics. $26,434 - 1 year. Paul Wilson, Dept of Agricultural & Resource Economics, D. Phillip Guertin, School of Natural Resources, Sharon Megdal, Water Resources Research Center/Dept of Agricultural & Resource Economics.
3. Arizona Project WET Evaluation: Examining Impact and Developing a Computer-based Tutorial and Assessment System $49,979 – 1 year. Jerome D'Agostino, Dept of Educational Psychology and Kerry Schwartz, Water Resources Research Center.
4. Brine Minimization/Salt Management Using VSEP® Technology to Maximize Water Recovery. $49,945 – 1 year. Eric Betterton, Dept of Atmospheric Sciences, Robert Arnold and Wendell Ela, Dept of Chemical & Environmental Engineering.
5. Compound Specific Isotope Analysis of Natural Attenuation Activity in Chlorinated-Solvent Contaminated Aquifers in Arizona. $23,834 – 1 year. Mark Brusseau, Dept of Soil, Water & Environmental Science.
6. Promoting the Adoption of Subsurface Drip Irrigation by Arizona's Farmers. $61,280 – 3 years. James Walworth, Dept of Soil, Water and Environmental Sciences, Edward Martin, Dept of Agricultural and Biosystems Engineering, Patrick Clay, Maricopa County Cooperative Extension, Mary Olsen, Division of Plant Pathology & Microbiology, Department of Plant Sciences, and Russell Tronstad, Dept of Agricultural and Resource Economics.

<u>WSP Funded WRRC Directed Initiatives</u>

In addition to the WSP projects conducted in-house or hosted by the WRRC, WSP funding has provided opportunities for the WRRC to strengthen educational programs, support new and continuing projects, and expand ties to other departments and colleges in the area of water policy and management. WRRC provided support to David Adelman, Associate Professor in Roger's College of Law, with a focus on environmental law and for Chris Scott (Geography/Udall Center) for research on urban warming and residential water demand, complementing a USGS 104(b) grant he was awarded in 2007. In addition, Prof. Scott's student, Kerri Jean Ormerod, received bridge funding for a grant funded project on public attitudes to water reuse. Former Associate Director Carl Bauer also was supported by WSP-WRRC funds. WRRC-WSP money funded half of two Translational Science Fellows sponsored by the Institute for the Study of Planet Earth (ISPE): Janick Artiola and Eric Betterton. In addition, Dr. Graciela Schneier-Madanes, chairman of "rés-EAU-ville" / CNRS (Centre National de la Recherche Scientifique), Paris, France has spent the 2007-2008 academic year at UA, hosted by WRRC and the Udall Center, as part of a new collaborative agreement with the French Government. In the fall of 2008, WSP-WRRC Directed Initiatives funds were used to produce a five-minute high-quality video for broadcast at the American Water Resources Association annual conference in New Orleans, November 17-20. The video, titled "Keeping Water Knowledge Flowing," showcases WRRC and WSP and is featured on the WRRC homepage. All footage is the property of WRRC and will be used to produce other video segments.

WRRC-WSP funding supported a number of research and outreach projects, including rainwater harvesting projects and development of a drought reporting system. Graduate students worked with Sharon Megdal on three projects: the Conserve to Enhance project, a concept that enables water users to apply conservation gains to environmental use; the Tucson Regional Water Planning Perspectives Study; and a project evaluating golf course water conservation policies. Another graduate student has been working with Dr. Megdal to develop an international conference, scheduled for August 2009, to establish a collaborative research agenda among Israeli, Palestinian, and Arizona water managers and university researchers.

The WRRC continued its support of projects associated with enhanced drought preparedness planning for the Colorado River; and climate change adaptation for water managers. Directed Initiative funds are also supporting exploratory work in preparation for U.S.-Mexico Transboundary Aquifer Assessment Act implementation. Arizona Project WET education programs continued to receive support as well. The WRRC funding made it possible to publish a Spanish translation of the popular booklet, Arizona Know Your Water. The booklet was originally published as the product of a WSP grant. The WRRC also directed funds to help support Kristine Uhlman's video projects for NEMO that have won multiple awards. The WRRC provided support for the Desert Horticulture 2008 Conference and for the celebratory events marking the 50th Anniversary of the first graduations from the Department of Geography and Regional Development. Directed Initiative funds also were used to support several of the seminars and lectures described above.

ARIZONA PROJECT WET

Arizona Project WET Water Education Program

Arizona Project WET is a comprehensive water education program with a twelve-year history of successful teacher training. The Arizona Project WET program uses nationally recognized educator guides to deliver water education programs that meet Arizona Academic Standards. Water Education Workshops, developed with local education and water specialist partners, meet grade level specific instructional goals and bring relevancy to the subject of water education for each audience. Water resource materials used to develop workshops cover all water topics from the physical and chemical properties of water to something as specific as Central Arizona Project's junior priority status for Colorado River water. Workshops designed specifically for pre-service teachers are taught through UA, ASU and NAU. Through intensive train-the-trainer workshops, volunteer facilitators are also equipped to offer teacher/educator workshops that focus on water issues in their particular areas of the state. The

Arizona Project WET program is guided by an advisory council, which meets bi-monthly. The Council members are water specialists and stakeholders from statewide government agencies and private entities.

Teacher workshops and other Arizona Project WET activities are funded by grants from federal, state, county, city and public/private entities, and grant funds support on-going program evaluation to assess impact and expand appropriately. During the reporting period, 712 teachers participated in at least one of 49 six to sixteen-hour water education workshops held in 18 cities across Arizona. These teachers report reaching 85,042 students each year with water education. To the statement, "The workshop was excellent - one of the best I have ever attended" 91% agree or strongly agree. To the statement, 'The workshop was relevant and improved my knowledge 95% agree or strongly agree. Finally, to the statement, "I intend to become a better water steward as a result of this workshop," 95% agree or strongly agree.

An evaluation of an innovative online learning and assessment system to supplement Arizona Project WET resources was completed and will be made available to teachers for the 2009-2010 school year. The major conclusions of this study were that students increased their understanding of key concepts (very large pre- & post-test score differences), many students were unable to complete the module, the more of the module that was completed, the higher the test scores and teachers' comfort with online modules seemed to influence their student' success (level of completion, quiz scores). The computer module engages students of "internet age," offers imbedded assessment and allows students to work at their own pace. An article has been submitted to Science Educator Journal of the National Science Education Leadership Association.

Kerry Schwartz was co-author on the Arizona Conserve Water Educators Guide. During the reporting period APW has provided professional development on Arizona Conserve Water to 204 educators in twelve workshops. These educators reported that they reach 13,735 students each year. To the statement, "The workshop was excellent - one of the best I have ever attended" 91% agree or strongly agree. To the statement, 'The workshop was relevant and improved my knowledge 94% agree or strongly agree. Finally, to the statement, "I intend to become a better water steward as a result of this workshop," 95% agree or strongly agree.

Workshops

- "Middle School Field Study units for 6th 7th and 8th grades" Biosphere 2 student facilitators, Tucson Arizona, December 3, 2008
- "Water Conservation Workshop," Yuma Public Works Building, Arizona, November 14-15, 2008.
- "Use of Science Notebooks and Alternative forms of Assessment," Water Champions, Maricopa County Cooperative Extension Office, Phoenix, Arizona, November 13, 2008.
- "School Water Audit Training," Master Watershed Stewards, Tucson Arizona, October 29, 2008.
- "Verde Valley Water Festival," Deadhorse Ranch State Park, Cottonwood, Arizona, October 23, 2008.
- "Payson Water Festival," Green Valley Park, Payson, Arizona, October 10, 2008.
- "Tucson Water Festival," Jacobs Park, Tucson, Arizona, October 3, 2008.
- "Flagstaff Water Festival," Thorpe Park, Flagstaff, Arizona, September 30, 2008.
- Invited Professional Development, "Water Education for High School Ag Ed Teachers," Best Western, Payson, Arizona, September 26, 2008.
- "Water Festival Unit for 4th Grade Verde Valley Teachers," Deadhorse Ranch State Park, Cottonwood, Arizona, September 25, 2008.
- "Classroom Management skills for inquiry based science," Water Champions, Maricopa County Cooperative Extension Office, Phoenix, Arizona, September 6, 2008.
- Invited Professional Development, "Full Option Science System Integrated Water Kit Training," Tucson, Sunnyside and Flowing Wells Unified School District 3rd Grade Teachers," Tucson, Arizona, July 28-29, 2008.

- "An Advanced Water Education Workshop: What Happens to the Water We Use? – Sewersheds and Salinity," ASU Decision Center for a Desert City, Tempe, Arizona, July 8-9, 2008.
- Facilitated: "Weather & Water FOSS Kit Discussion Group," Tucson and Sunnyside Unified School District 6th Grade Teachers, Tucson, Arizona, June 26, 2008.
- "The Colorado River: An Arizona Perspective Workshop," in conjunction with the Water Resources Research Center Annual Conference, Phoenix, Arizona, June 24-25, 2008.
- Invited Professional Development, "6th Grade Water and Weather Workshop," Peoria Unified School District, Peoria, Arizona, May 28, 2008.
- Invited Professional Development, "Yuma K-8 English Language Learner Vocabulary Development Using Arizona Project WET," Yuma District 1, Yuma, Arizona, May 17, 2008.
- "Payson Water Festival," Green Valley Park, Payson, Arizona, May 2, 2008.
- Invited Professional Development, "Full Option Science System Integrated Water Kit Training," Tucson Unified School District 3rd Grade Teachers," Tucson, Arizona, April 29 & May 6, 2008.
- "Water Champions" 3-day workshop, South Mountain, Gilbert Riparian, and North Mountain Parks, Phoenix, Arizona, April 24-26, 2008.
- "Who Owns the Verde?" Arizona Foundation for Resource Education/Arizona Project WET Joint Field Study, Phoenix-Cottonwood, April 19, 2008.
- "Water Festival 4th Grade Teachers," Payson Teachers, Payson, Arizona, April 18, 2008.
- "Arizona Conserve Water," Randolph Golf Course, Tucson, Arizona, April 12, 2008.
- "Science Methods using Arizona Project WET," NAU Preservice Teachers Chandler-Gilbert Community College, Chandler, Arizona, April 10 & May 1, 2008

Arizona Makes a Splash with Project WET Water Festivals Program

Arizona Make a Splash with Project WET Water Festival program supports local communities in organizing standards-driven water education events for fourth graders. Arizona Project WET developed the Arizona Water Festival Program in 2000. These 4th grade standards-based water education events have now engaged and instructed 26,397 students and 1200 teachers in throughout Arizona. Managed by Holly Hilburn, this reporting period water festivals reached 5,017 students, and 393 teachers. Lessons were conducted by 388 trained volunteers. During this reporting period a Bureau of Reclamation grant to conduct a summative program assessment has enabled the collection of thousands of pre- and post-festival tests from participating students. Initial analysis shows that students' scores on a test of their water knowledge improved significantly after experiencing an Arizona Water Festival, and that in particular students knowledge of and intent to conserve water increased as a result of the experience. Communities regularly holding festivals include Flagstaff, Phoenix metro area, Tucson, Yuma, Sierra Vista, Safford, Payson, and now Cottonwood and Nogales.

ARIZONA NEMO (Nonpoint Education for Municipal Officials)

Arizona NEMO is a program to provide technical support and outreach to communities and land use decision makers in Arizona. With a strong focus on water quality concerns, Arizona NEMO watershed based planning documents characterizes each watershed with GIS mapping and includes predictive numeric modeling to simulate watershed response and to predict nonpoint source transport. The Arizona NEMO program has developed watershed based planning documents for nine of the twelve large watersheds of the state with funding provided through Federal Clean Water Act, Section 319, under the direction of the Arizona Department of Environmental Quality. Planning documents, maps, and a manual of Best Management Practices (BMPs) can be found at the NEMO website (www.AirzonaNEMO.org).

ADEQ renewed the Arizona NEMO contract through 2010 to complete the modeling and mapping of the remainder of the state and the publication of the NEMO Watershed-Based Planning documents. In

addition, the new scope of work includes upgrading of the NEMO Internet Mapping Service (IMS) to provide state-wide coverage of GIS maps, hydrologic data, and water quality information. Under this new scope the NEMO team will be providing workshops across the state on IMS tools, Best Management Practices (BMPs) to improve watershed health, as well as supporting the development of Watershed Implementation Plans.

MASTER WATERSHED STEWARDS PROGRAM

Since the summer of 2008, the office of Arizona's Master Watershed Stewards Program has been located at the WRRC. Administered within UA Cooperative Extension and funded by the U.S. Environmental Protection Agency and Arizona Department of Environmental Quality, the program educates and trains citizens across the state of Arizona to serve as volunteers in the protection, restoration, monitoring, and conservation of their water and watersheds. Association with this program extends WRRC's information and education outreach through this statewide network. Cooperative activities, such as facilitating the participation of watershed groups in the WRRC's annual conference, provide mutual support, multiplying the benefits to the served communities.

NOTABLE ACHIEVEMENTS AND AWARDS

- Sharon Megdal was awarded the C.W. and Modene Neely Endowed Professorship for Excellence in Agriculture and Life Science at the UA College of Agriculture and Life Sciences in March 2008. The professorship was endowed to recruit or retain a distinguished scholar to further critical research, teaching and extension in areas relating to water. In naming Dr. Megdal for the award, the College recognized her work in UA water programs and commitment to water education, outreach and research in Arizona and the Southwest.
- "NEMO Wet/Dry Video" won Bronze award from the National Association of Resource Extension Professionals Group I 2008.
- Jackie Moxley was appointed to the Community Advisory Board of Tucson Green Times and to the University of Arizona, Campus Sustainability Communications Committee.
- Kristine Uhlman who was elected Chairperson for the Watershed Subcommittee by the Pima Association of Governments (PAG). PAG is the association of government jurisdictions in Pima County.
- An article by Tony Davis that appeared in the Arizona Daily Star, July 16, 2008, entitled "UA idea: Tucsonans save water; funds go to restore our rivers, Why conserve water when what's saved goes to serve more growth?" featured Conserve-to-Enhance research and prototype conservation program work by Dr. Megdal and graduate students, including current Masters student, Joanna Bate.
- Carl Bauer gave an invited paper about water markets in Chile at the Expo Zaragoza Water Tribune, an international water fair in Zaragoza, Spain, in July 2008 (http://www.expozaragoza2008.es/). He took part in a week-long conference about Water Economics and Finance: The Role of Market Instruments in Integrated Water Management, with leading Spanish and international experts, and was interviewed by Spanish radio and web journalists.
- Carl Bauer taught a four-hour graduate class on "Water markets in the U.S. and Chile" at the Colegio de Sonora in Hermosillo, Sonora, Mexico, in May 2008. The class was for a graduate program in Integrated Management of River Basins. While in Hermosillo he also met with staff-people of the Mexican Government's National Water Commission, at their request, to discuss issues of water banks; two staff-people traveled from Mexico City for this meeting.

- UA News featured the Video, “UA Trains Students to be Water Stewards,” on their website, October 8, 2008. The video showed students and teachers experiencing an Arizona Project WET Water Festival hosted by Water Resources Research Center.
- The main feature in the AWR newsletter, November - December, 2007, "Wanted: A Viable Biofuel Crop in Semi-arid Arizona" was reprinted in the September 2008 Arizona Agricultural Experiment Station Research Report, under the title “Sweet Sorghum into Ethanol-Adapting an alternative fuel crop for Arizona
- The supplemental insert, “Arizona NEMO: Integrated Watershed Management and Planning,” in the May-June 2006 issue of AWR is being re-published as Chapter 8 in Watershed Management Concepts and Experiences, S. Menon and P. Pillai, Eds., Icfai University Press (www.books.iupindia.org) Hyderabad, India.
- J.J. Riley made a presentation and led a discussion on water harvesting to an audience composed of community and university members at the Science Café on January 13, 2009. The session was one of the most well attended events in the Science Café series. Articles about the presentation were printed in UA News and the Tucson Citizen Newspaper.
- J.J. Riley was the central guest on an Access TV program on August 20, 2008, where he presented work on water harvesting on the UA.

PRESENTATIONS

Resulting from 104(b) and 104(g) research grants

1. Dejwakh, N. Michalski, G., Meixner T. McIntosh, J. Using □ 17O to differentiate atmospheric from terrestrial sources of nitrate and estimate denitrification’s influence on Tucson’s groundwater, presented 18th annual El dia Del Agua, March 6, 2008.
2. Halper, Eve, City of Tucson Landscape Advisory Committee workshop, May 15, 2008.
3. Halper, Eve, “Correlating urban water demand, remotely sensed surface temperature and vegetation in an arid environment,” American Association of Geographers Annual Meeting, Boston, Massachusetts, April 15-19, 2008.
4. Philips, C.F., M. Marikos, J.J. Riley, R. Rushforth, E. Brill-Duisberg, W. Leith, “Raising a Green Umbrella: Parasol’s Collaborative Model for Sustainability at the University of Arizona,” Soil and Water Conservation Society 2008 Annual Conference, July 26-30, 2008.
5. Riley, J.J., "Harvesting the Sky-Rainwater, An Important Source of Water for Tucson," Science Café, Flandrau: The UA Science Center and the Science Café, January 13, 2009.
6. Riley, J.J., B. Lancaster, A. Audrey, G. McCormick, E. Scharf, and Chester Phillips, Rainwater, an important source of water for arid lands Catch it! Symposium on Rainwater Harvesting at annual conference of the Soil and Water Conservation Society, July 26-30, 2008, Tucson, Arizona.
7. Rushforth, R., L. Davis, L. Perino, G. McCormick, L. Davison, J.J. Riley, “Promoting Campus Sustainability through Interdisciplinary Cooperation: The Greening of the University of Arizona Visitor Center,” Soil and Water Conservation Society 2008 Annual Conference, July 26-30, 2008.
8. Scott, Christopher, “Tucson urban heat island and vegetation indices,” GEOG 490/590 Remote Sensing for the Study of Planet Earth, The University of Arizona, May 1, 2008.
9. Scott, Christopher, Eve Halper, Stephen Yool, Andrew Comrie, “The evolution of urban heat island and water demand,” Eighth Symposium on the Urban Environment at the 89th American Meteorological Society Annual Meeting, January 11–15, 2009, Phoenix, Arizona.
10. Scott, Christopher, Eve Halper, Stephen Yool, Andrew Comrie, “Water demand under urban heat island and climate change in Tucson, Arizona, 2000-2006,” Changing Waterscapes and Water Ethics for the 21st Century, Arizona Hydrological Society and American Institute of Professional

Geologists, 3rd International Professional Geology Conference, September 20 – 24, 2008, Flagstaff, Arizona.

11. Yool, Stephen, Climate change, related production of green house gases, and regional water and energy budgets, City of Tucson's Environmental Management, September 23, 2008.

Presented by WRRC professional staff

1. Bauer, Carl, Research on hydropower development, electricity regulation, and water law in Chile, UA, Spring 2008.
2. Eden, Susanna, Lessons learned in SAHRA's decision support experience, SAHRA Eighth Annual Meeting: Securing the SAHRA Legacy, October 16-17, 2008.
3. Megdal, Sharon, Presentation, "Forming Scientific Collaborations," ADVANCE Career Discussion Series, University of Arizona, Tucson, AZ, February 19, 2009.
4. Megdal, Sharon, "Water Policy Challenges in Arizona," Superfund Colloquium, University of Arizona, Tucson, AZ, February 12, 2009.
5. Megdal, Sharon, "Water Program Connections between Science and End Users," Translational Environmental Research Symposium, University of Arizona, Tucson, AZ, February 9, 2009.
6. Megdal, Sharon, "Water Resource Management and Planning in the Tucson Region," Arizona-Sonora Desert Museum Educational Program for Volunteer Docents, Tucson, AZ, February 4, 2009.
7. Megdal, Sharon, "Asymmetries in the Regulation of Private versus Public Provision of Water in Arizona," Water Governance: The Public-Private Debate, University of Arizona, Tucson, AZ, February 4, 2009.
8. Megdal, Sharon, "Meeting the Long-Term Needs of the Central Arizona Groundwater Replenishment District," Water Rights, Sales and Transfers in Arizona, Lorman Continuing Education Program, Tucson, AZ, January 28, 2009.
9. Megdal, Sharon, "Evolution and Evaluation of the AMA Management Plans," Phoenix AMA Groundwater Users Advisory Council, Phoenix, AZ, January 6, 2009.
10. Megdal, Sharon, United States-Mexico Transboundary Aquifer Assessment Program, Water Resources Research Center Brown Bag Seminar (with C. Scott, J. Callegary and P. Vandervoet), December 8, 2008.
11. Megdal, Sharon, Commentary, "Issues the CAP Board will Face," KUAT TV, Channel 6, Tucson, Arizona, December 3, 2008.
12. Megdal, Sharon, "Water Management in Arizona: Focus on the Tucson Region and Green Valley," La Posada Speakers Forum, Green Valley, AZ, November 21, 2008.
13. Megdal, Sharon, "The Quest for Long-Term Water Resource Planning," American Water Resources Association National Conference, New Orleans, LA, November 19, 2008. (Abstract published in Proceedings.)
14. Megdal, Sharon, "Conserve to Enhance: Voluntary Municipal Conservation to Support Environmental Restoration," American Water Resources Association National Conference, New Orleans, LA, November 17, 2008. (Abstract published in Proceedings.)
15. Megdal, Sharon, "Water Management and Policy in Arizona," Flinn Scholars, Tucson, AZ, October 4, 2008.
16. Megdal, Sharon, Water Resource Availability for the Tucson Region, City/County water and Wastewater Study Oversight Committee, Tucson, AZ, October 2, 2008.
17. Megdal, Sharon, Water Planning in the Tucson Region, Green Valley Coordinating Council, Green Valley, AZ, October 2, 2008.
18. Megdal, Sharon, Water Sustainability in Arizona: Can We Achieve It? The Honors College Forum, University of Arizona, Tucson, AZ, September 29, 2008.
19. Megdal, Sharon, "Tucson Regional Water Planning Perspectives Study," City/County water and Wastewater Study Oversight Committee, Tucson, AZ, August 27, 2008.
20. Megdal, Sharon, Water Issues in the Tucson Region, Congresswoman Gabrielle Giffords' Town Hall on Water, Sahuarita, Arizona, July 1, 2008.

21. Megdal, Sharon, Water Policy in the Tucson Region, Tucson Metropolitan Chamber Board of Directors, Tucson, AZ, June 23, 2008.
22. Megdal, Sharon, Update on the U.S.-Mexico Transboundary Aquifer Assessment Program, Water Committee, Arizona-Mexico Commission, Phoenix, AZ, June 20, 2008.
23. Megdal, Sharon, Urban Water Management: Present and Future, Eau de Paris, Paris, France, June 11, 2008.
24. Megdal, Sharon, Planning for Arizona's Growing Water Demands, Arizona Desert Horticulture Conference, Tucson, AZ, May 16, 2008.
25. Megdal, Sharon, The UA Water Sustainability Program and the Programs of the Water Resources Research Center, Water Summit, College of Agriculture and Life Sciences, Tucson, AZ, May 1, 2008.
26. Megdal, Sharon, and Joanna Bate, Conserve to Enhance, WRRC Brown Bag Seminar, Tucson, AZ, April 3, 2008.
27. Megdal, Sharon, Santa Cruz County and Transboundary Water Planning, Zonta International Club, Nogales, Arizona, April 2, 2008.
28. Megdal, Sharon, Understanding the Economics of Water Allocation, The Economics of Water and the Environment Workshop for High School and Middle School Teachers, The Thomas R. Brown Foundation and Arizona Council on Economic Education, Tucson, AZ, March 31, 2008.
29. Megdal, Sharon, Water Planning and Management in the Tucson Region, Real Estate Professionals Group of the Jewish Federation of Southern Arizona, Tucson, AZ, March 25, 2008.
30. Megdal, Sharon, Are We Running Out of Water?, Annual Overview of the Real Estate Market, Fox Theatre, Tucson, AZ, March 4, 2008.
31. Moxley, Jacqueline, The University of Arizona Keeps Water Research and Knowledge Flowing, Little Colorado River Watershed Coordinating Council, Winter Watershed Meeting, January 29, 2009.
32. Moxley, Jacqueline, The UA Water Sustainability Program, Arizona Water Pollution Control Association, Research Priorities Workshop, Phoenix, March 7, 2008.
33. Schwartz, Kerry, "The Urban Steward Program" for the Arizona Municipal Water Users Association, Phoenix, Arizona, December 9, 2008.
34. Schwartz, Kerry, An Abbot Fund Arizona Project WET Partnership, for the Abbot staff, Casa Grande, Arizona, November 21, 2008.
35. Schwartz, Kerry, The Arizona Project WET Program in Yavapai County, for the Yavapai County Water Advisory Committee, Cottonwood, Arizona, November 19, 2008. Invited
36. Schwartz, Kerry, Water Festival Model Training for Volunteers, Yuma, Arizona, November 3, 2008.
37. Schwartz, Kerry, Water Festival Model Training for Volunteers, Cottonwood, Arizona, October 20, 2008.
38. Schwartz, Kerry, An Online Innovation to Enhance Instruction and Assess Learning, North American Association of Environmental Education Conference, Wichita Kansas, October 17, 2008.
39. Schwartz, Kerry, Poster, Arizona Project WET Water Champions: A New Lens to View the World, North American Association of Environmental Education Conference, Wichita Kansas, October 16, 2008.
40. Schwartz, Kerry, Water Festival Model Training for Volunteers, Payson, Arizona, October 7, 2008.
41. Schwartz, Kerry, Water Festival Model Training for Volunteers, Tucson, Arizona, September 29, 2008.
42. Schwartz, Kerry, The Arizona Project WET Program, for the Coconino Water Advisory Group Meeting, Flagstaff, Arizona, September 26, 2008.
43. Schwartz, Kerry, "Educating the Public About Water using Project WET, UCOWR/NIWR Annual Conference – International Water Resources Challenges for the 21st Century & Water Resources Education, Durham, North Carolina, July 22-24, 2008.
44. Schwartz, Kerry, The Arizona Water Festival Program, for the Santa Cruz Active Management Area, Ground water Users Advisory Committee (GUAC), Nogales, Arizona, July 2, 2008.

45. Schwartz, Kerry, Water Festival Volunteer Training, for Volunteers, Payson, Arizona, April 17, 2008.
46. Schwartz, Kerry, Water in Arizona, IRIS Earth and Space Science Professional Development Project, Yuma Union High School District, April 16, 2008. (Invited)
47. Schwartz, Kerry, Systems Thinking and Water, 2nd Annual BIO5 Science Teacher Symposium, University of Arizona, April 5, 2008.
48. Uhlman, K., NEMO Watershed-Based Plans and Watershed Management Tools, Hohokum Resource Conservation and Development (RC&D), Mesa, Arizona 05/13/08; Little Colorado Watershed (New Mexico and Arizona) Annual Conference, Show Low, Arizona 01/31/08; Tucson, 01/15/09
49. Uhlman, K., with L. Levick, T. Sprouse, E. Westfall, and C. Holmgren, Arizona NEMO Wet/Dry Mapping of Arizona Perennial Rivers, workshop presentations and training, Benson 06/21/08, Arcosanti - Cordes Junction 05/03/08, and 06/21/08 and BioSphere 2, Arizona Rivers Summer Camp, Tucson, Arizona 06/18/08.
50. Uhlman, K., Well Log Reporting for Drillers, a full-day workshop addressing geologic logging in the construction of water wells, with Janick Artiola, Mohave County Extension, Arizona Department of Water Resources, and the Northwest Watershed Partnership, Kingman, Arizona, 11/18/2008.
51. Uhlman, K., Finding NEMO in your Stormwater and Community Outreach Toolbox, a 2-day workshop introducing NEMO to EPA Region 10 (Alaska, Idaho, Washington and Oregon), Washington State University, Tacoma, Washington, 10/7/2008.
52. Uhlman, K., Where does your water come from? New Mexico Cattle Growers, RioDoso, New Mexico 06/17/08.
53. Uhlman, K., Where does your water come from? Presidio Charter Chapter of the American Business Women's Association, Tucson, Arizona, 05/13/08.
54. Uhlman, K., Where does your water come from? Rotary Club presentations: Benson, 08/23/06, South Tucson, 09/07/07, Tucson, 09/10/07, and Saddlebrook, 03/27/08, 04/08/08 and 05/13/08.
55. Uhlman, K., Where does your water come from? Arizona/New Mexico Coalition of Counties, Silver City, New Mexico, 03/29/08; Little Colorado and Show Low Creek Watershed partnership, Pinetop/Lake-Side, 09/11/08; Cochise County Supervisor's Water 101 Lecture Program, Benson, 10/30/08; Coronado RC&D, Willcox, 11/12/2008; Arizona Rural Water Association, Laughlin Nevada, 02/04/09.
56. Uhlman, K., NEMO Program and Live Website Demonstration, Conservation Resource Management Team of State and Federal Land Managers, Phoenix, Arizona, 4/6/2008.
57. Uhlman, K. and Erin Westfall, NEMO IMS Mapping Workshop, Safford, 01/23/09.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	24	2	0	0	26
Masters	5	1	0	1	7
Ph.D.	3	2	0	0	5
Post-Doc.	0	0	0	0	0
Total	32	5	0	1	38

Notable Awards and Achievements

ARIZONA'S GROUNDWATER MANAGEMENT PLANNING EVALUATED A report by Sharon Megdal and graduate student, Aaron Lien, presents the results of their AWI funded research into the evolution of Active Management Area (AMA) groundwater management plans under the Arizona Groundwater Management Act. More than half-way into the 45-year period for meeting the goals of the Act, the Arizona Department of Water Resources (ADWR) will be developing the fourth of five management plans for each of the AMAs, as mandated by the Act. Tremendous efforts by ADWR staff, those regulated by ADWR, and other water stakeholders are devoted to the development of the management plans. This report provides an examination and assessment of effectiveness relative to goals and provides recommendations for future management plans. This will be used to assist ADWR as it moves forward with the development of the Fourth Management Plans.

WATER CONSERVATION BANKING: A PROGRAM OF WATER CONSERVATION FOR ENVIRONMENTAL ENHANCEMENT In the arid southwestern United States, many environmental enhancement activities require supplemental irrigation water and securing the needed water can be a barrier to the implementation or continuation of environmental enhancement activities. Few mechanisms currently exist to address this need for environmental water supplies. A report by Sharon Megdal and former graduate student Andrew Schwartz introduces the concept of a Water Conservation Banking program given the name "Conserve to Enhance." Water Conservation Banking refers to voluntary municipal water conservation programs designed to increase water efficiency and generate revenue to support environmental enhancement activities. Activities following on the introduction of the Conserve to Enhance concept are planned to develop a prototype demonstration. With another graduate student, Joanna Bate, Dr. Megdal has been presenting the concept at listening sessions and collecting feedback on implementation ideas. Partnerships with environmental groups and other stakeholder organizations in the Tucson area have been developed.

RAINWATER HARVESTERS REACH INTO THE COMMUNITY Students in the class on rainwater harvesting created by James J. Riley, UA associate professor of Soil, Water and Environmental sciences, have developed water harvesting plans for selected sites on and off the UA campus and contributed hand-on time to create passive rainwater harvesting features. Prof. Riley developed his class and related hands-on activities supported in part by WRRC grants. On-campus projects capture water from UA parking lots and streets to mitigate flooding and decrease irrigation demand. Off-campus, the lessons from the activities at a local elementary school are being integrated into the curriculum with the goal of teaching students to develop and test solutions to the problems they investigate.

In 2000, Prof. Riley and his students organized the Symposium on Water Harvesting at the national conference of the Soil and Water Conservation Society. Held in Tucson, Arizona, July 26-30, 2008, the symposium was entitled, "Rainwater, an important source of water for arid lands—Catch It!" In addition to Prof. Riley, presenters included Ann Audrey, Coordinator, City of Tucson, Office of Conservation and Sustainable Development; Eric Scharf, Principal, Wheat Sharf Associates; Brad Lancaster, Author: Volumes I and II of Rainwater Harvesting for Drylands and Beyond; Grant McCormick, University of Arizona Campus and Facilities Planner; and Chet Phillips, founder of PARASOL, a student environmental organization.

Ex-students have gone on to involve themselves further in rainwater harvesting through the non-profit Watershed Management Group. This Tucson-based organization is partnering with UA and others to bring water harvesting workshops and other assistance to residents, neighborhoods and communities.

ASSISTANCE TO WATERSHED GROUPS YIELDS WATER QUALITY IMPROVEMENTS Water quality improvements have been realized under the Arizona NEMO program, a partnership between the Water Resources Research Center and the Arizona Department of Environmental Quality. Watershed management

plans for each of Arizona's watersheds have been developed to support the implementation of best management practices to improve surface water quality. Under this program, NEMO has provided support to five community applicants resulting in eleven successful grants funded under Clean Water Act Section 319(h) for a total of approximately $1,475,000 towards water quality improvement projects across the state.

SUMMER WRITING INTERNSHIP AT THE WRRC INAUGURATED Through the sponsorship of Montgomery & Associates, Water Resource Consultants, a Tucson based consulting firm, the WRRC initiated a competition open to students at all three Arizona universities for a summer writing internship. The task of the student awarded the WRRC summer writing internship in 2008 was to work on the upcoming edition of the Arroyo. Claire Landowski, the first recipient of the summer internship was a member of the team that developed the 2009 Arroyo on water reuse was. A comprehensive look at the history, regulation, treatment, and uses of reclaimed water, the Arroyo describes new strategies for water reuse, along with the latest results of relevant university research projects, and explores public policy issues relating to treatment and distribution costs, incentives, and the protection of public health with reclaimed water for various uses, including potable reuse. Claire interviewed water professionals, university researchers, and citizen activists and made site visits to reuse treatment and recharge facilities for her research. The results of her work with the writing team will be published in early 2009. A competition for the second Montgomery & Associates Summer Writing Internship at the WRRC was held in March.

ARIZONA PROJECT WET ON-LINE CURRICULUM HAS SIGNIFICANT IMPACT ON WATER KNOWLEDGE An evaluation was carried out to assess the use and effectiveness of an innovative online learning and assessment system developed to supplement Arizona Project WET classroom resources. Study authors concluded that students increased their understanding of key concepts, as indicated by the very large differences in pre- and post-test score of students completing the module. Not all students completed the module, and evaluators found that the more of the module completed, the higher the test scores. Study results will be made available to teachers for the 2009-2010 school year. The educational resources of Arizona Project WET are directly linked with Arizona's student learning standards and training in the use of these resources was provided to more than 900 teachers during the reporting period.

Publications from Prior Years

1. 2007AZ213B ("Sources of Nitrate in Groundwaters of the Tucson Basin ") - Dissertations - Dejwakh, N. Sources of Nitrate to Tucson Groundwaters, MS Thesis. Department of Hydrology and Water Resources University of Arizona, Tucson, Arizona 2008.
2. 2007AZ190B ("Riparian Vegetation Response to Cessation of Groundwater Pumping, Lower San Pedro River, Arizona") - Book Chapters - Katz, G.L., J. Haney, C. Paradzick, D. B. Harris. Mitigation, restoration, and endangered species: restoring river flows to the Lower Basin. In J.C Stromberg and B. Tellman (editors) Ecology and Conservation of the San Pedro River. University of Arizona Press. 2009.